Poultry Products Processing

An Industry Guide

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To my wife Ilana

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PREFACE

THIS book provides comprehensive coverage of the modern poultry processing industry for people currently working in the field and students or newcomers wishing to learn about this rapidly developing industry. The book covers all areas of modern further processing, starting with catching and hauling poultry, the operation of a primary processing plant, inspection, grading, meat processing (including chapters on equipment, formulations, preservation, and breaded products), poultry meat microbiology, sanitation, HACCP (including a detailed description of new guidelines for raw, cooked and breaded products), reviews of poultry meat color (including a trouble shooting guide), flavor, sensory, functional properties and by-products. In addition, there is a chapter on basic avian anatomy and muscle biology, to assist the reader in understanding the fundamental aspects of meat quality and processing.

The goal of this book is to provide a thorough review of the world poultry industry today. Coverage includes the major poultry meat producing species, chicken and turkey, and also duck, geese, pigeon and ratite meat. There are numerous cross-references and a list of additional reading at the end of each chapter. New trends, such as machine vision for automated grading, are discussed in order to help the reader understand the basis for past and future development.

It is hoped that this book will provide a valuable resource for personnel working in the dynamic area of further processing, including management, quality control, and sanitation personnel, food technologists, meat specialists, ingredient and equipment suppliers, as well as students and others new to the field.

I would like to thank a number of individuals who assisted me during the process of writing the book. First, to my friend and colleague, Howard Swatland, for his continuous support and encouragement to write the book. I would also like to thank the people who reviewed parts of the book and provided valuable comments: Larry Binning, Wayne Brightwell, Valerie Davidson, Ian Duncan, Chris Findlay, Carolyn Hamilton, Ed Halford, Chris Haworth, Theo Hoen, Walter Knecht, Mohan Raj, Robert Rust, John Summers, Uwe Thode, Bethany Uttaro, and Diane Wood.

I would like to make special mention of Kim Rawson whose continuous help in entering data, illustrations, revisions, and editing has contributed so much to the production of the book. I would like to thank Alex Galvez for providing the front cover artwork, Ori and Gal Barbut for illustration work and the editors at the Technomic Publishing Company for their support and guidance.

Overall, the development of the poultry processing area has been a team effort involving many talented individuals. It would be impossible to mention them all here, but one of them is my former advisor at the University of Wisconsin, the late Arthur J. Maurer, whose enthusiasm and guidance were invaluable to the development of my career.

If you have any comments/suggestions, I would appreciate hearing from you. You can contact me at my home page—http://surf.to/poultry.

CHAPTER 1

Poultry Meat Processing and Product Technology

INTRODUCTION

POULTRY meat is consumed all around the world and, over the last few decades, has increased in popularity in many countries. Among the reasons for this increased consumption are the relatively low costs of production, the rapid growth rate of poultry, the high nutritional value of the meat and the introduction of many new further processed products. Overall, the poultry industry has changed dramatically over the past 50 years. In the early 1900s, most poultry in the western world was produced in small flocks mainly to supply eggs to support small farm units, and the eggs and live birds' by-product of the egg enterprise were sold live in local markets. Today, the poultry industry is highly integrated and managed by a number of large corporations. Computers are used to formulate diets (e.g., least cost feed formulations), forecast market trends, control meat processing equipment, and lately, also to operate machine vision used for automatic inspection and grading. The Internet and E-commerce are starting to play a major role in marketing. For example, in the summer of 2000, some of the major North American meat processors created on-line business-to-business marketing for poultry meat.

In the early 1900s, the same chicken breed was used for both meat and egg production, with little or no selection. Over the years, the poultry industry has grown and specialized in meat production and egg production breeds, as will be discussed later in this chapter. In addition, farmers have started to specialize in certain aspects of raising poultry and, today, it is common to find operations specializing in only one phase of the growing stage (e.g., breeding, hatching or meat production). Modern growing operations are usually fairly large and house a few hundred thousand to a few million birds at one location. Such operations require precise management control and must run efficiently in order to be profitable. Vertical integration of poultry operations has been another major change in the structure of the poultry industry. Such an integration usually starts with the hatchery, moves through to the growing operation, which includes the feed mill, and moves to the processing plant. This helps to streamline the operation and makes production more cost effective and competitive. This book focuses on the further processing aspects and includes discussion of factors affecting meat quality such as growing conditions, catching and transportation.

The further processing segment is rapidly developing with the integration of automated equipment, advances in food science, food microbiology, engineering and marketing. Past achievements have been the contribution of many individuals, and further advances will require the cooperation of technologists, scientists and businesspeople. The industry is still facing many challenges, and the way they are handled will determine the efficiency and competitiveness of the poultry industry compared to other meat and non-meat protein sources. Such challenges include live bird catching and hauling, where reduction in the amount of bruising and improving worker conditions are critical. The use of new automated catching equipment will be discussed, as well as the monitoring and control of environmental conditions on the truck during transportation. In the processing plant, various changes are taking place today, where stunning methods are re-examined, and the use of gas stunning is starting to emerge. In the further processing area, new formulations that include gums, coating materials and sophisticated cooking equipment are constantly being developed. Today, emphasis is put on food safety and on the implementation of hazard analysis critical control point (HACCP) programs in order to meet new government regulations. Processes such as irradiation are gaining acceptance as part of the overall goal to reduce foodborne illnesses. In addition, animal welfare issues are becoming more important today on the political agenda, and public concern has promoted various groups to demand changes in the handling and processing of poultry. In places such as Europe, representatives from large supermarket chains are visiting growing and processing facilities to ensure proper handling of live birds and, in some cases, are demanding changes.

The industry has done a tremendous job increasing the popularity of poultry meat around the world. Maintaining this position will require innovations, new ideas and strategies in the ever-increasing competitive food market. These are really exciting times for the poultry industry, and the goal of this book is to assist people already in the business and newcomers in gaining an overview of the entire industry. In addition, emphasis has been placed on providing students with background material that will allow them to understand fundamental aspects, such as poultry biology, muscle structure and conversion of muscle to meat.

PRODUCTION

Poultry meat is produced all over the world. Figures 1.1 and 1.2 show the major areas of the two most commonly produced poultry species, namely chicken and turkey. Chicken production is concentrated in four major areas (Figure 1.1). In North America, about 44% of the world's production, or

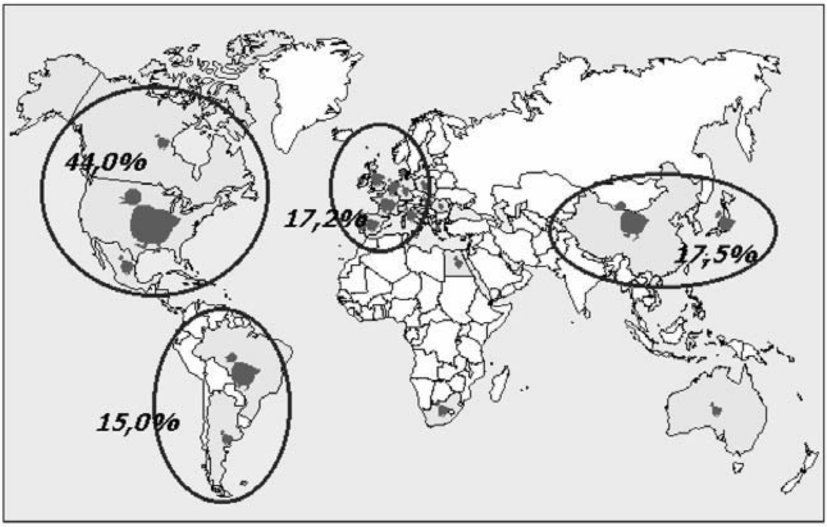

Figure 1.1. World Chicken Production in 1996. From French Meat Industry Center (2000).

14,000 million tons, were produced in 1996. The United States produced 12,160, Mexico 1,120 and Canada 710 million tons. Asia produced about 5,550 million tons, with China accounting for 4,400 and Japan 1,150 million tons. Western Europe produced 5,460 million tons, with France accounting for 1,150, United Kingdom 1,016, Spain 840, Italy 693. The Netherlands 580,

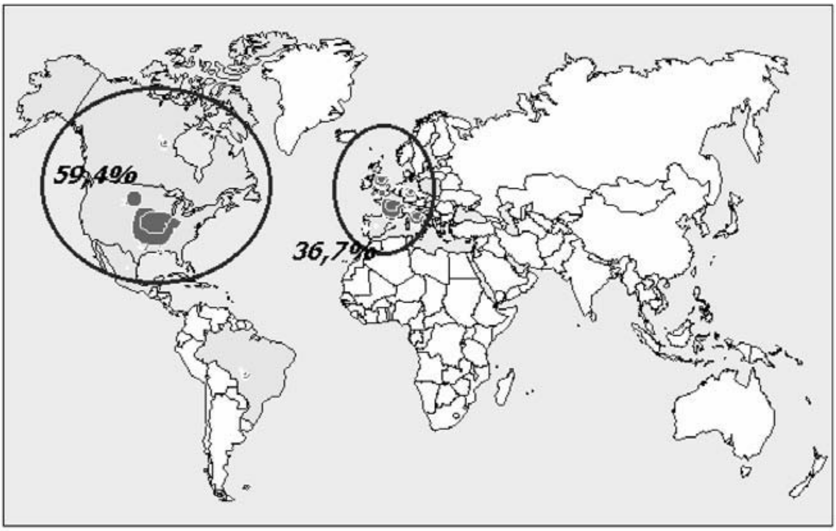

Figure 1.2. World Turkey Production in 1996. From French Meat Industry Center (2000).

Germany 350, Belgium 255, Portugal 200, Denmark 155, Greece 146 and Ireland 70 million tons. In South America, 4,780 million tons were produced, in Brazil 4,130 and in Argentina, 650 million tons. Other countries such as South Africa produced 647 million tons, Australia 453, Egypt 34, Hungary 218 and Poland 190 million tons.

Turkey production is concentrated in three major areas (Figure 1.2). In North America, 2,630 million tons were produced, in the United States 2,480 and in Canada 143 million. In Western Europe 1,625 million tons were produced, in France 680, Italy 310, United Kingdom 280, Germany 215, Portugal 42, Ireland 33, The Netherlands 28, Spain 17, Denmark 10 and Greece 3 million tons. Other countries were Brazil with 100, Poland 49 and Hungary 27 million tons.

Figure 1.3 shows changes in turkey production in selected countries over the period 1987 to 1997. The figure illustrates continuous growth of over 50% during that period. The highest production was in the United States, where turkey meat is very popular and represents about 18% of the total meat consumed, as will be later discussed.

Chicken is the species most commonly produced around the world, followed by turkey and, to a much lesser degree, by other species. Table 1.1 shows the common commercially available poultry along with their market age, their average carcass weight and their ready-to-cook (RTC) weight. In certain areas of the world, such as Southern Asia, duck production represents a very significant segment of total poultry production. Local species of pigeons and quail have been an important staple in the diets of people in the Middle East for many centuries. Meat production from several "exotic species" such as ostrich and rhea are becoming more popular as these species are

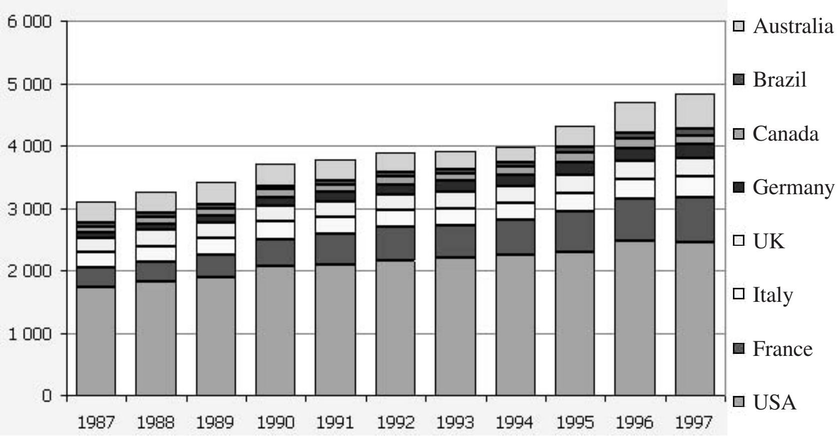

Figure 1.3. *Turkey Production (Metric Tons) in Some Major Countries. From French Meat Industry Center (2000).*

Table 1.1. Types of Commercially Available Poultry and Their Average RTC[a] Weight.

Type	Age (Weeks)	Weight RTC (kg)
Chickens		
Broiler or fryer	6–8	1.2–1.7
Roaster	8	3.0
Rock Cornish game	3–4	0.6
Hen/stewing fowl	>52	1.1
Cock or mature rooster	>30	2.2
Turkeys		
Broiler hen	10	4.2
Young hen	16	7.0
Young tom	17–18	12.5
Spent breeder	>52	11.0
Ducks		
Broiler or Fryer	7	2.5
Geese		
Mature	12–16	5
Guineas		
Mature	12	1.5
Pigeons	4–5	0.4
Quail	7	0.15
Ratite		
Ostrich	40–55	55
Rhea	44–48	62

[a] RTC = Ready-to-cook weight (i.e., body weight excluding feathers, blood, digestive tract, head and feet).

raised on commercial farms in countries such as Australia, South Africa, Israel, Canada, the United States and Zimbabwe.

Poultry production figures for 1998, of selected countries, are presented in Table 1.2. Some of the main changes from the 1996 figures (not presented) result from the significant increases in broiler production in China (4,400 to 5,460, respectively) and in Brazil (4,130 to 4,490). These changes represent the growing popularity of poultry meat in China and the increase in exports from Brazil. One of the main reasons for Brazil increasing its exports is its large increase in corn and soybean production, thus resulting in relatively low production costs. Table 1.3 shows that Brazil had one of the lowest producing costs in 1997. Data from Aho (1996) indicate that Brazil enjoyed very low feed and plant labor costs (Figure 1.4). This obviously gives Brazil an advantage over other countries, making it one of the major players in the poultry export market. Countries like the United States, due mainly to their relatively low feed costs (Figure 1.4), are also competitive on the international trade market. Another example from South Asia is Thailand, where low plant labor costs have

Table 1.2. Poultry Production in Selected Countries (1998). Reported in 000 Metric Tons. From U.S. Department of Agriculture (1999).

Country	Broiler	Turkey
United States	11,515	2,395
China	5,460	NA
Brazil	4,490	107
France	1,235	732
United Kingdom	1,144	275
Japan	1,075	NA
Canada	710	139
The Netherlands	648	57
Australia	524	NA
Russian Federation	1,142[a]	NA

[a] Estimates for 1995. NA = not available.

allowed it to be a major exporter to markets such as Japan. Figure 1.4 can be divided into four major zones with regard to overall production costs. Brazil had the lowest costs in 1996, with China and the United States having similar production costs when combining feed and plant labor costs, while Argentina, Turkey and Thailand make up a third group with similar overall costs. Finally, the countries on the right side of the figure have high production costs, thus excluding them from the export market. The above is very important in understanding world trade in poultry meat, as will be discussed later in this chapter.

Table 1.3. Cost and Wholesale Price (Per kg) Comparison of Broiler Production in Various Countries (1997). From Mulder and Schlundt (1999).

Country	Raising Costs (U.S. Cents)	Wholesale Price (U.S. Cents)
United States	57	123–213
Brazil	55	94–108
China	80	133
Thailand	100	140
France	90	205–442
The Netherlands	83	194–320
Japan	132	287–1,021
Russian Federation	185	265
Saudi Arabia	222	379
Sweden	110	270–400
Finland	152	412

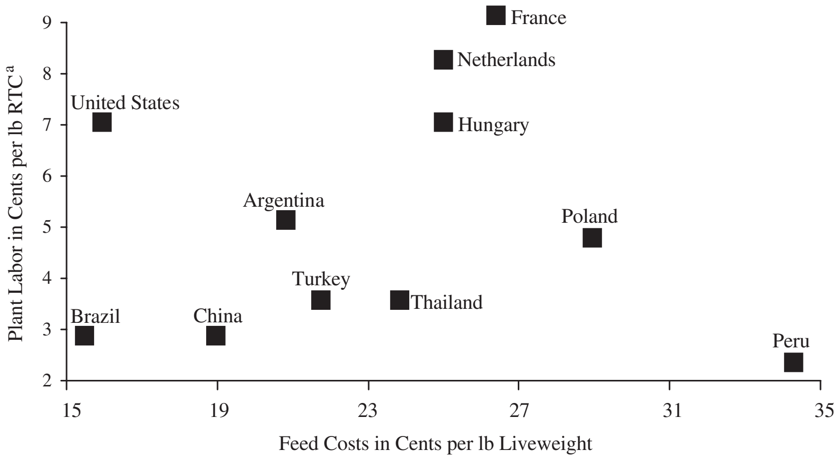

Figure 1.4. *Poultry Production Competitive Advantage. From Aho (1996). With Permission from Watt Publishing. [a]RTC = Ready to Cook.*

While the human population is currently increasing at 1.4% per year, it is forecasted to increase by an average of 1.2% to 2020, reaching 7.7 billion. Urbanization is increasing, and incomes are rising in many parts of the world. Both of these trends are associated with increased per capita demand for meat that is increasing at a faster rate than population growth (CAST, 1999). Per capita meat consumption for 1983 and 1993, and a projection for 2020, are presented in Figure 1.5. The projection for 2020 is based on a model developed by the International Food Policy Research Institute for developed and developing countries. Although, as recently as the 1980s, people in the developing world consumed just over one-third of the global meat supply, they are now consuming closer to half. By 2020, this group is forecasted to be consuming 63% of total meat production. Per capita consumption is forecast to be little changed in the developed world, increased by more than 50% in developing countries, and almost doubled in China. Various factors could influence this projected increase, a major one being the current relatively low meat intake of some countries.

Urbanization is also associated with an increased demand for animal products. On the average, the rate of people moving to cities is 3.5% per year in developing countries vs. 0.75% in developed countries (CAST, 1999). Higher average incomes are another important factor directly affecting increased demand for meat. In the past two decades, industrialization and higher incomes have been greatest in Asia, where the largest increase in meat consumption has been seen. The annual rate of increase in meat demand, from the early 1980s to 1990s, was 5.4% in Asia, with the exception of India and China, compared to 1.8% in the United States and an even smaller increase in Europe. China

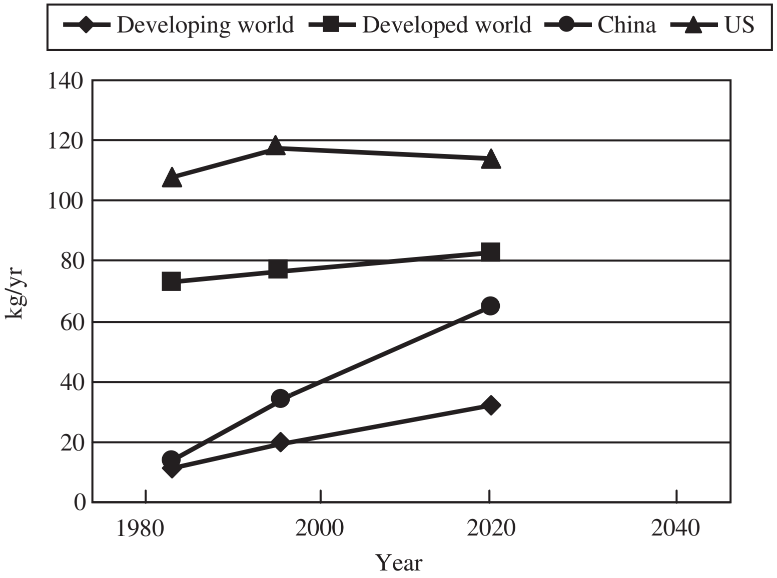

Figure 1.5. *Per Capita Meat Consumption (kg/yr). From FAO data in Delgado et al., 1998. Report by CAST (1999). With permission.*

has experienced an 8.3% increase, while India, for religious and cultural reasons, retained its preference for vegetarian diets. If the Indian preference should change to any significant extent, its population that is rapidly approaching one billion, would have a major effect on world livestock markets.

Recent growth in consumption of different meats and projected figures are presented in Table 1.4. In developed and developing countries, the largest recent and projected increases are in poultry meat. The high annual growth rates in poultry, pork and beef in developing countries (7.4, 6.1 and 2.8%, respectively, for 1983 to 1993) are not expected to be sustained; however, rates above 2% per year are projected for these meats in developing countries through 2020. As a result, developing countries are projected to produce more meat than developed countries. Higher demand in developing countries is expected to increase imports from various developed countries, which will be discussed later in this chapter.

Looking into the future, we must remember the achievements and changes experienced by the poultry industry during the last century. Table 1.5 shows tremendous improvement in selecting and raising meat-type broilers. Whereas, in the early 1900s, it took about 120 days (17 weeks) to raise broilers to a live weight of 1 kg, with a feed:gain ratio (kg feed/kg weight gain) of 5.0:1; today, it takes an average of 50 days (7 weeks), with a target live weight of 2.6 kg and a feed:gain of 1.9:1. This has been the result of significant selection for meat-type producing broilers. In addition, advances in pharmaceutical

Table 1.4. Past and Projected Production Trends of Various Meats, to the Year 2020.[a,b]

Region	Annual Growth of Production 1983–1993	Projected Annual Growth of Production 1993–2020	Total Production 1983	Total Production 1993	Total Production 2020	Per Capita Consumption 1983	Per Capita Consumption 1993	Per Capita Consumption 2020
	(%/yr)		(Mt)			(kg)		
Developed								
Poultry	2.8	1.2	17	26	37	14	20	27
Beef	0.4	0.8	32	33	40	27	25	29
Pork	0.9	0.4	35	37	42	29	29	30
Meat	1.2	0.8	92	100	124	77	78	89
Developing								
Poultry	7.4	3.0	9	21	46	3	5	7
Beef	2.8	2.4	17	22	42	4	5	7
Pork	6.1	2.8	21	39	84	6	9	13
Meat	5.2	2.7	51	88	182	15	21	29

[a] Sources: Delgado et al., 1998. Raw data prior to 1995 from FAO (9/17/97), and projections to 2020 from a model described by Delgado. From CAST (1999). With permission.

[b] Meat includes beef, pork, mutton and goat and poultry. Annual growth of meat production 1982–1993 is the compound growth rate from regressions fitted to FAO annual data. Metric tons and kilograms are three-year moving averages centered on the year shown.

Table 1.5. Growth Characteristics of Mixed-Sex Broilers Grown to Typical "Market Weights." From Leeson and Summers (2000). With Permission.

Time Period	Age (Days)	Live Wt (kg)	Live Wt Gain (g/Day)	Feed:Gain	Mortality (%)
1920s	120	1.0	8	5.0:1	20
1930s	100	1.2	12	4.6:1	15
1940s	85	1.4	17	4.0:1	10
1950s	75	1.5	20	3.2:1	8
1960s	70	1.6	23	2.5:1	8
1970s	60	1.9	32	2.2:1	5
1980s	50	2.2	44	2.0:1	5
1990s	50	2.6	51	1.9:1	4

products and husbandry practices have resulted in dropping mortality from 20% in the early 1900s to about 4% today. This has allowed the industry to become much more competitive and cost efficient as compared to red meat sources. For comparison purposes, it should be noted that a common feed:gain ratio for pork production is about 5:1, and it takes 8–12 months to market. For beef, feed:gain is around 7:1, and it takes 12–24 months to reach market weight. In the case of beef, it should be mentioned that grazing and foraging diets (high in fiber, which is undigested for monogastric animals such as poultry and pork) can result in a relatively low feed cost for cattle.

Table 1.6 also illustrates some of the major changes in the way agriculture is practiced today in various western countries. The example is from Ontario, but it is applicable to many other areas. One of the major changes is the huge reduction in the number of farmers raising poultry. The table shows that the number has been reduced by 98.5% over a 40-year period. In the early 1950s, farmers used to keep small backyard flocks that supplied them with poultry and eggs for their own farm consumption and some for sale at local markets. Today, such operations are almost nonexistent, and the average poultry operation size is measured in thousands. While the price of meat has increased over the years, as would be expected by increases in living costs, it is interesting to note that the actual price the consumer pays (after adjusting for inflation) is much lower today than it was 50 years ago. Egg production data is also shown in the table in order to illustrate the major advances in egg production and the separate selection programs designed to improve egg-producing lines. Egg prices have also significantly decreased (after adjusting for inflation) over the past 50 years as a result of technological advances in genetics, nutrition, management and disease control.

Table 1.6 also shows the tremendous increase in chicken production in Ontario. Half a century ago, 4.5 million people consumed 10 kg of poultry meat per person/year. In 1991, 10 million people consumed 30 kg/year, which was

Table 1.6. Changes in the Poultry Industry and in Ontario's Agriculture. Adapted from Surgeoner and Leeson (1993).

	1951	1991
Ontario population (M)	4.5	10
Farms (poultry/eggs)	100,000	1,500
Chicken[a] (kg)	10	30
Chicken production (M-kg)	45	300
Price (kg)	C$1.4	C$4.2
Adjusted for inflation[b]	C$8.2	
Eggs[a]	280	214
Egg production (M-doz)	107	180
Price (doz)	C$.72	C$1.50
Adjusted for inflation[b]	C$4.3	
Eggs/hen	160	290
Feed efficiency (kg/doz)	3.4	1.6

[a] Per person year.

[b] Price index increased 498%.

mostly raised in the same area. This obviously represents significant economical growth, but it has also put pressure on the environment. Problems such as pollution are receiving more attention today, and certain countries, such as the Netherlands, are currently limiting or even reducing animal production.

It should also be mentioned that the present number of around 1,500 poultry farms in Ontario is probably relatively high compared to similar production in the United States. This is mainly due to political differences, where in Canada, the existence of Marketing Boards is still providing room for some small/medium-sized farms. This is different from in the United States, where a relatively smaller number of large corporations are responsible for raising most of their broilers. When it comes to further processing plants, the situation on both sides of the border is fairly similar, where few large plants are employed to process all of the area's poultry production.

CONSUMPTION

Poultry meat consumption varies around the globe, where various factors affect consumers' demand. Among these factors are consumer preference, tradition, price and source of feedstuff available. Figure 1.6 shows broiler consumption in selected countries. At the top are Hong Kong, the United States and Israel, followed by Saudi Arabia, Singapore and Canada. It is interesting to note that in countries such as the United States, where total meat consumption is

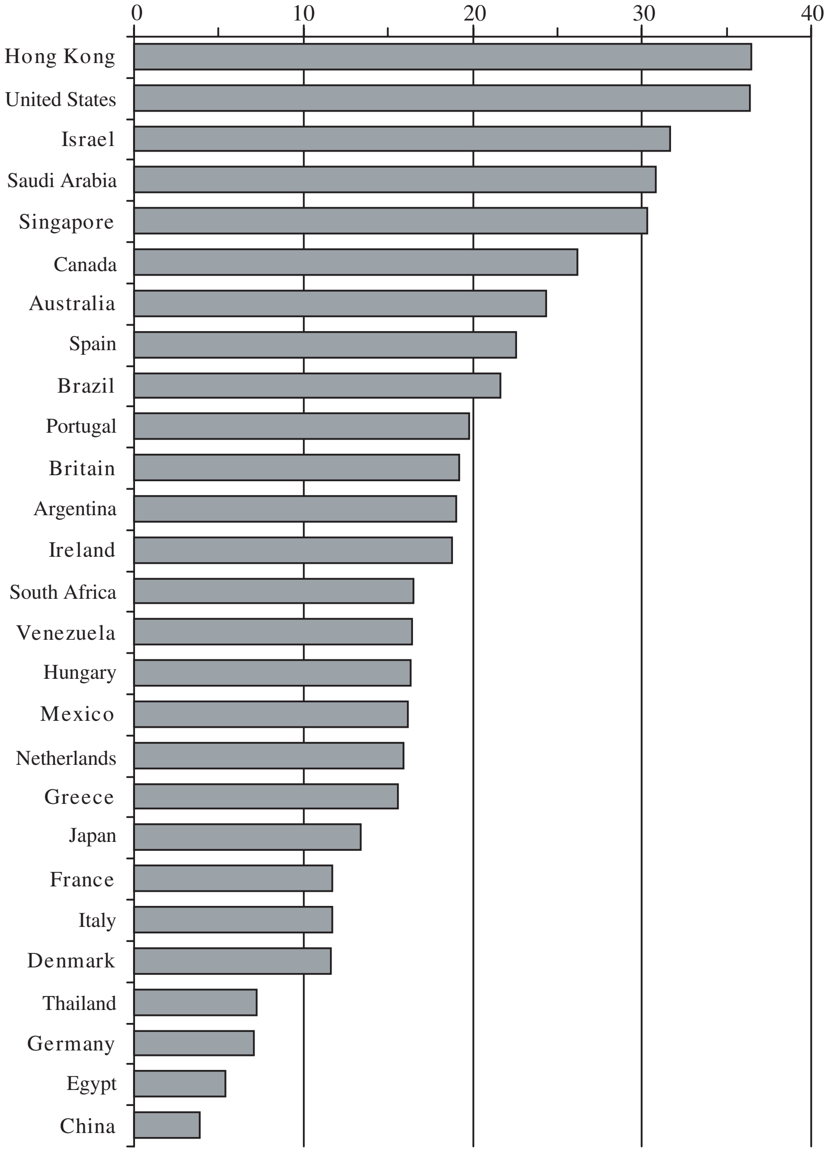

Figure 1.6. *Chicken Meat Consumption (kg per Capita) in Selected Countries during 1996. From U.S. Department of Agriculture (1999).*

high (Figure 1.5), a lot of poultry is consumed. In other countries such as Israel and Saudi Arabia, where pork meat is unpopular because of religious concerns, poultry meat consumption is very high.

Turkey meat consumption is shown in Figure 1.7, indicating that the highest consumption is in Israel, followed by the United States and France. Again,

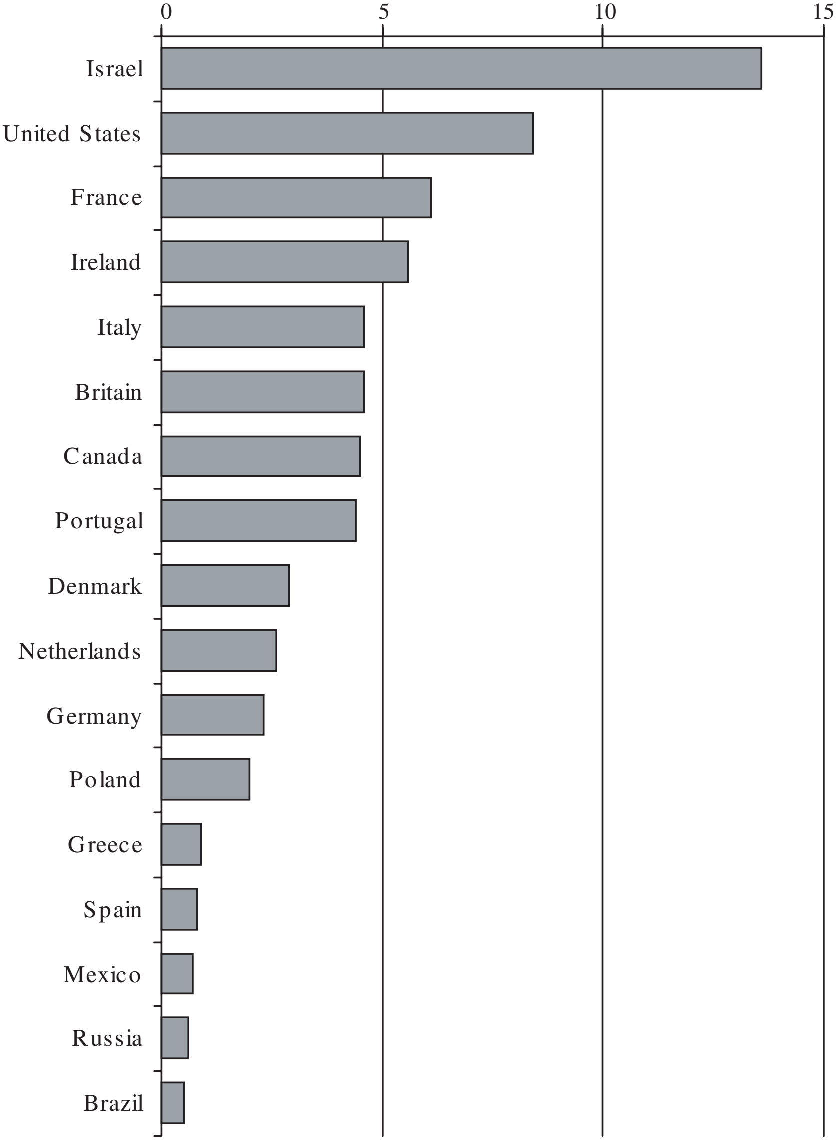

Figure 1.7. *Turkey Meat Consumption (kg Per Capita) in Selected Countries during 1996. From U.S. Department of Agriculture (1999).*

some of the factors contributing to high demand are religious concerns, while others are tradition and relative cost.

It is also important to study trends in poultry meat consumption within the same region. Figure 1.8 shows changes in some of the European Union countries between 1984 to 1996. In all countries, an increase in poultry meat

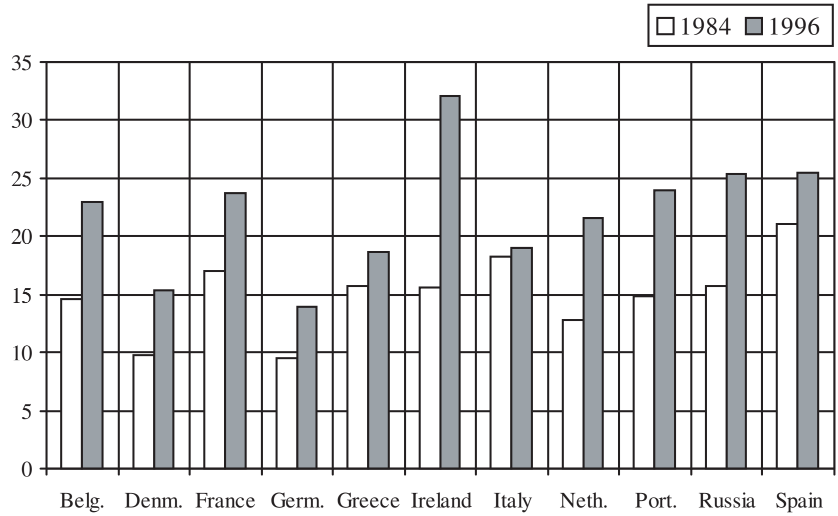

Figure 1.8. *Changes in Poultry Meat Consumption (kg Per Capita) in Some European Union Countries. From French Meat Industry Center (2000).*

consumption has been observed, but the highest was seen in Ireland. This is encouraging for the poultry industry and has resulted from the introduction of new further processed products, marketing of cut-up poultry (e.g., a package of a single turkey drumstick suitable for a small family) and the development of favorable consumer perception toward lean poultry meat. In other countries such as Japan, which was and still is a major fish and seafood consuming country, total poultry and red meat consumption have increased nearly five-fold from 1965 to 1995 (Figure 1.9). The increase in poultry meat consumption has been as significant as that of pork and beef. This is a tremendous change in the eating habits of a nation over a period of 30 years.

The relative changes in meat consumption patterns in the United States are shown in Table 1.7. It is interesting to note that the relatively flat poultry consumption figure of 17 lb/capita/year of the 1940s, doubled after the second World War to 34 lb in 1960. Poultry meat consumption doubled again in the United States over the next 20 years and reached almost 60 lb in 1980. By 1998, poultry meat consumption increased by one-third over the 1980 figure. Beef and pork consumption figures are presented for comparison reasons. It can be seen that poultry meat has replaced some red meat over the years and is representing a major competitor to red meat. Some of the main reasons for the shift seen in meat consumption trends are as follows:

- significant reduction in production costs
- introduction of new further processed products (e.g., poultry hot dogs, which were unavailable in the market 30–40 years ago)

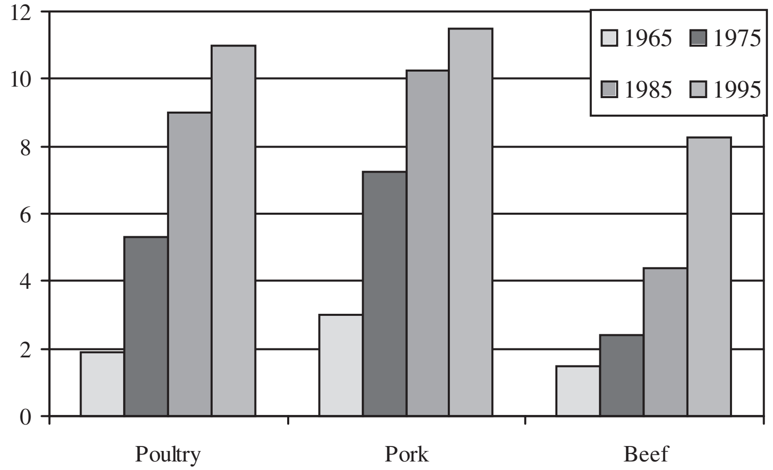

Figure 1.9. *Changes in Japanese Meat Consumption (Per Capita, kg/yr). From French Meat Industry Center (2000).*

- changing consumer demand patterns (A prime example is the total change in turkey meat sales in North America and Europe, which moved from a seasonal pattern consisting of major peaks around Thanksgiving and Christmas, to year-round sales.)
- introduction of products with small portions, such as a single turkey drumstick in a package (This change was apparently necessary to sell products to small families.)
- offering of convenient deboned and/or marinated products that do not require excessive preparation (Today, products such as fully seasoned barbecue skewers are available for purchase that only require opening the package and placing the skewers on the barbecue.)

Table 1.7. Per Capita Consumption (in lb) of Poultry Meat in the United States. Based on Retail Disappearance. From the U.S. Department of Agriculture.

Year	Chicken	Turkey	Poultry (Total)	Beef	Pork
1910	NA	NA	15.0	51.0	NA
1940	NA	NA	17.0	50.0	68.0
1960	26.5	6.5	34.0	69.4	60.3
1970	40.6	8.1	48.7	84.6	56.0
1980	48.8	10.3	59.1	76.6	57.3
1990	63.0	17.6	80.6	67.8	49.8
1998	73.9	18.1	91.1	68.1	52.6

NA: not available.

- offering ground meat products, such as lean ground turkey (e.g., turkey hamburger patties, emu patties), to compete with the traditional ground beef product
- introduction of new products with a healthier image [A fairly recent entry is turkey bacon, which is made from layers of white and dark meat (see also Chapter 8). Another example is turkey-ham, which is made from dark turkey thigh meat and is promoted as a leaner product compared to traditional ham. It is interesting to note that the introduction of new products such as turkey-ham was not without opposition from groups manufacturing traditional ham, who tried to challenge in court the use of the term "ham" for a poultry product.]
- consumer education campaigns showing the consumer that poultry products can be made with less fat and that poultry fat is more unsaturated [The latter is often mentioned in diet guidelines as being preferred over saturated fat. In addition, poultry meat does not have marbling (unlike red meat species), and removing abdominal and subcutaneous fat can result in extremely lean cuts of meat.]

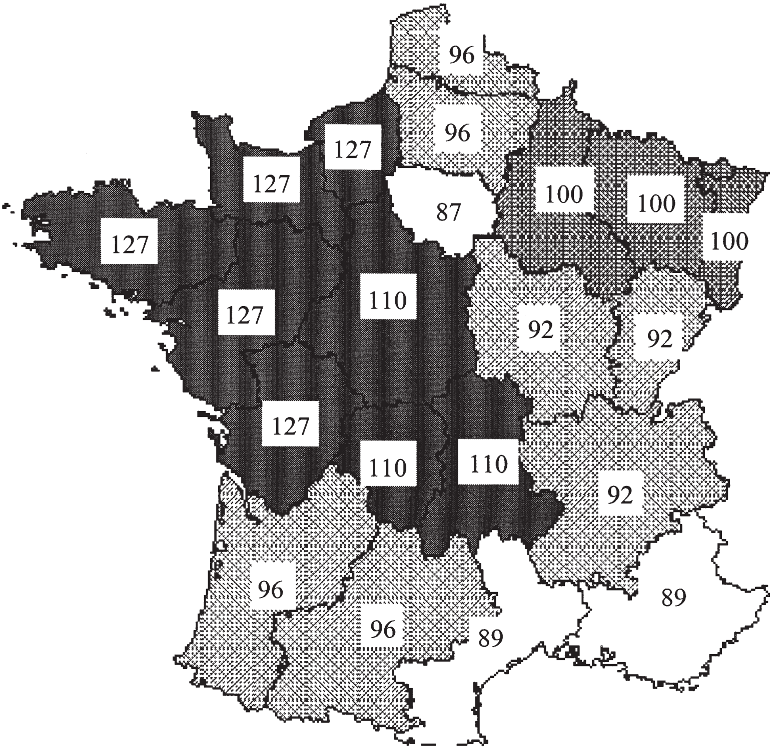

__Figure 1.10.__ Household Purchases of Turkey Meat in Different Regions in France during 1996 Compared to a National Average (100%). From French Meat Industry Center (2000).

All of these factors helped to give poultry meat a healthy image and, in combination with inexpensive prices, resulted in increased consumption (Figure 1.8). However, it should be remembered that a national per capita consumption figure can vary within different regions (Figure 1.10). This figure illustrates a fairly wide variation in consumption of turkey meat in various parts of France. A similar figure for chicken meat consumption (not presented here) indicates that the variations in chicken meat are not as great and are usually close to the national average (numbers vary from 95–108% with the majority of regions consuming 100 ± 3% of the national average). The reasons

Table 1.8. Poultry Consumption Trends in Several European Countries and the United States. From French Meat Industry Center (2000).

Country		1991	1992	1993	1994	1995	1996	1997
Belgium	Turkey	2.5	2.5	2.1	2.4	3.0	3.4	3.4
	Level (%)	100.0	100.0	84.0	96.0	120.0	136.0	136.0
	Poultry	17.2	18.1	18.2	21.4	23.1	22.1	21.0
	% Turkey	14.5	13.8	11.5	11.2	13.0	15.4	16.2
Britain	Turkey	4.1	3.9	4.6	4.7	4.9	5.1	5.1
	Level (%)	100.0	95.1	112.2	114.6	119.5	124.4	124.4
	Poultry	19.9	21.2	20.2	21.8	25.1	26.2	25.5
	% Turkey	20.6	18.4	22.8	21.6	19.5	19.5	20.0
France	Turkey	5.8	6.2	5.7	5.6	6.4	5.9	5.6
	Level (%)	100.0	106.9	98.3	96.6	110.3	101.7	96.6
	Poultry	21.9	21.9	20.9	22.3	22.6	23.8	24.0
	% Turkey	26.5	28.3	27.3	25.1	28.3	24.8	23.3
Germany	Turkey	3.0	3.4	3.4	3.6	4.0	4.4	4.7
	Level (%)	100.0	113.3	113.3	120.0	133.3	146.7	156.7
	Poultry	12.2	12.5	12.4	12.8	13.4	14.1	14.5
	% Turkey	24.6	27.2	27.4	28.1	29.9	31.2	32.4
Greece	Turkey	0.5	0.4	0.6	0.7	0.8	0.9	0.9
	Level (%)	100.0	80.0	120.0	140.0	160.0	180.0	180.0
	Poultry	16.7	18.2	18.0	18.5	17.7	19.8	20.3
	% Turkey	3.0	2.2	3.3	3.8	4.5	4.5	4.4
Ireland	Turkey	4.0	4.0	5.4	5.3	5.6	6.7	6.7
	Level (%)	100.0	100.0	135.0	132.5	140.0	167.5	167.5
	Poultry	23.3	23.5	25.3	27.7	30.9	31.3	32.0
	% Turkey	17.2	17.0	21.3	19.1	18.1	21.4	20.9
The Netherlands	Turkey	2.0	2.2	2.3	2.5	2.7	2.5	2.7
	Level (%)	100.0	110.0	115.0	125.0	135.0	125.0	135.0
	Poultry	17.7	18.5	18.9	20.0	20.4	21.4	21.8
	% Turkey	11.3	11.9	12.2	12.5	13.2	11.7	12.4
United States	Turkey	8.2	8.2	8.1	8.1	8.1	8.4	8.0
	Level (%)	100.0	100.0	98.8	98.8	98.8	102.4	97.6
	Poultry	41.8	43.4	44.6	45.3	45.1	46.1	46.6
	% Turkey	19.6	18.9	18.2	17.9	18.0	18.2	17.2

for the different consumption figures can range from cultural differences to availability of certain meats in different regions.

Changes in poultry consumption in different European countries and in the United States are shown in Table 1.8. It can easily be seen that the proportion of chicken vs. turkey meat in different countries is quite variable. For example, in Greece, turkey meat consumption represents about 5%, and in France, 25%. Overall, changes in poultry meat consumption differ greatly among countries. Greece has experienced an 80% increase in turkey meat consumption, whereas France and the United States have seen a slight decline of 3–4% between 1991 and 1997. But, in both France and the United States, this decline was more than compensated for by an increase in chicken meat consumption.

TRENDS IN POULTRY MEAT MARKETING

The relative price of poultry meat has decreased over the years in the western world (Table 1.6). An example of the situation in the United States is presented in Table 1.9. The absolute retail price for 1 lb of a whole fryer has increased from 41.7¢ in 1970 to 104.4¢ in 1998. Similarly, the wholesale and retail spread has increased. However, the relative expenditure for poultry and red meat (combined figure) has decreased from 4.2% to 2.0% of disposal income from 1970 to 1998, even though total meat consumption has increased over the same period of time. This is the result of improved efficiencies in poultry production, as previously discussed.

Major changes have also occurred in the way poultry meat is marketed (Figure 1.11). At the beginning of the 1900s, most poultry in the western world was sold live or slaughtered only (i.e., not eviscerated). This is still the situation in some of the developing countries where traditional customs and/or lack of refrigeration dictate selling live birds. Figure 1.11 shows that a sharp decline in the sale of whole birds has occurred during the past 40 years in the United States. Whole birds, which used to be about 85% of the market in the early 1960s, dropped to about 15% of the market by the end of the century. The proportion of cut-up and parts has increased threefold from 15–45%. The proportion of further processed products has increased more than tenfold. This trend continues today as a higher proportion of further processed poultry products are sold to the consumer as convenient food items.

Changes in The Netherlands and Germany also indicate the same trend (Figure 1.12). The sale of whole chicken as a percentage of the total has declined in The Netherlands from 34% to 22% between 1994 and 1998, and in Germany, it declined from 69% to 58% during the same period of time. The percent of chicken sold as cut-up or parts has proportionally increased. The differences in marketing between the two countries illustrate differences in consumption habits. In general, the poultry industry is usually quick to re-

Table 1.9. Information on Chicken Prices in the United States and Their Relative Cost to the Consumer (1970–1998). From U.S. Department of Agriculture (1999).

	Cost Per 1 lb of Whole Fryer			Expenditure		
					Poultry and Red Meat	
Year	Retail Price (¢)	Wholesale (¢)	Retail Spread (¢)	Poultry[a] Per Capita (¢)	% of Disposable Income	% of Total Food Cost
1970	41.7	29.8	11.8	19.7	4.2	26.0
1975	64.3	49.4	14.9	29.9	4.2	25.8
1980	71.9	53.5	18.5	50.1	3.6	23.5
1985	76.3	56.2	20.1	70.8	2.7	19.9
1990	89.9	60.5	29.4	103.9	2.4	17.8
1995	91.7	64.4	27.3	117.5	2.1	16.3
1998	104.4	71.0	33.4	129.5	2.0	15.8

[a] Chicken and turkey.

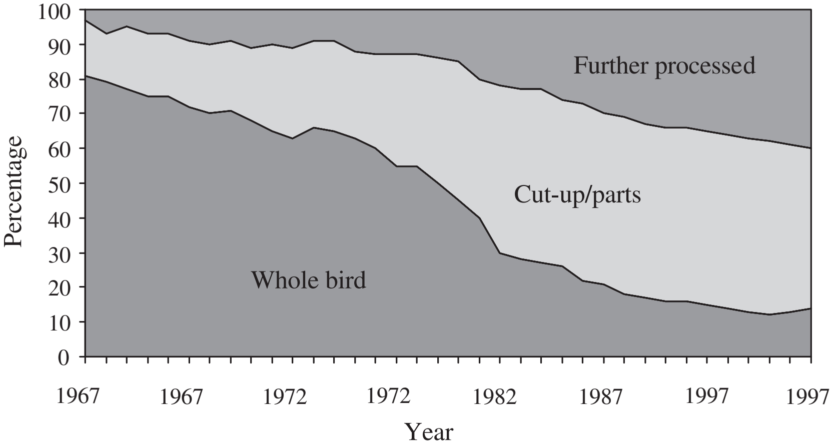

Figure 1.11. *Changes in Broiler Marketing in the United States from 1962 to 1997. From Smith (1999). With Permission from Watt Publishing. Based on Data from the U.S. National Chicken Council.*

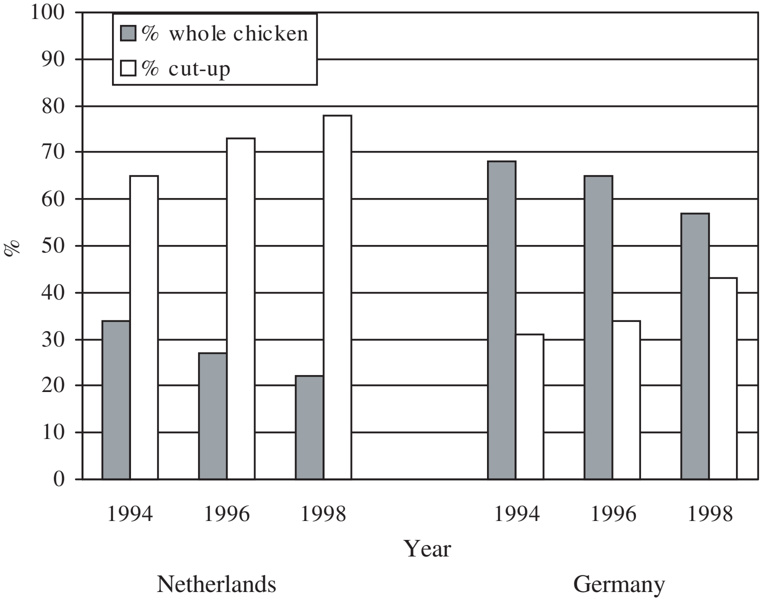

Figure 1.12. *Consumption of Whole Chicken vs. Cut-Up in The Netherlands and Germany. Adapted from Uijttenboogaart (2000).*

spond to changes in consumer preferences. It is expected that sales of cut-up chicken will increase faster in Germany than in The Netherlands, where a higher proportion of poultry is already sold as cut-up and parts.

A breakdown of cut-up and further processed products sold around the world is provided in Table 1.10. Distribution varies greatly among countries, however, further processed products sales represent roughly 13% across the world. This is small compared to the situation in North America, Europe and Japan. However, it also highlights the great opportunity for further processing to expand in regions where little further processing is presently done. Overall, markets continue to demand more value-added products, and this trend seems to be growing (Neuwirth, 1997).

The term "value-added products" refers to further processed products beyond the cut-up and ready-to-cook poultry. Increasing the consumption of value-added products represents a shift from poultry meat sold as a commodity item, to brand name value-added products sold at a premium. It appears that the food service business has substantially influenced the development and sale of convenience food items by introducing new products. One example is the chicken nugget that was introduced by one of the fast-food chains 2–3 decades ago and became a huge success story for the poultry industry. The nuggets are also currently sold in large quantities at retail stores in frozen form. In addition, convenient products such as entire dinners, entrees, appetizers and boneless marinated products have helped increase demand for poultry meat. Table 1.11 shows the relative distribution of food service and retail sales in different markets. Changing traditional buying habits and the movement toward more industrial societies are resulting in a higher proportion of food sold as further processed products. The fast-food industry,

Table 1.10. Estimates on Global Poultry Sales.
From Neuwirth (1997). With Permission.

	Whole Bird (%)	Cut-Up (%)	Further Processed (%)
North America	20	50	30
Asia	48	34	18
Europe	55	25	20
South America	76	19	5
Africa	50	45	5
Soviet Union	84	12	4
Eastern Europe	61	25	14
Oceania	38	40	22
Average	58	29	13

Table 1.11. Estimates on Global Poultry Marketing.
From Neuwirth (1997). With permission.

	Retail (%)	Foodservice (%)	Export (%)
North America	48	35	17
Asia	56	34	10
Europe	68	25	7
South America	64	28	8
Former Soviet Union	93	77	0
Eastern Europe	85	10	5
Oceania	67	32	1

which continues to expand, is undoubtedly helping the introduction and sale of poultry products around the world. An example is McDonald's, which has around 27,000 restaurants in 114 countries on five continents, serving 38 million customers a day. In 1999, about 2,000 new restaurants were built with only about 15% in the highly competitive North American market. One of the main regions for expansion was South America, where the number of stores almost doubled. In Japan, McDonalds opened its first restaurant in 1971, had 1,000 by 1993 and about 3,000 by 1999. This number is expected to at least double within the next decade, which obviously represents a major increase in the amount of further processed poultry product sales.

In order to stay competitive, the poultry industry must develop new products to satisfy emerging consumer demand. The increase in the number of new poultry products and poultry meal entrees in the United States is presented in Table 1.12. The number has more than doubled since 1993 in the poultry sector. The market is very competitive, and the poultry industry is competing with other meat sources as well as vegetarian entrees. Overall, one of the fastest growing segments in food retail is the frozen dinners and entrees category,

Table 1.12. New Entries of Poultry, Seafood and Red Meat Products in the United States. From Galosich (1997). With Permission.

	1996	1995	1994	1993
Poultry	202	85	132	68
Poultry meals and entrees	146	116	164	85
Fish	212	106	184	52
Fish meals and entrees	47	37	36	21
Meat	182	187	154	126
Meat meals and entrees	123	108	96	72
Totals	912	639	766	424

which reached total sales of $3.9 billion in 1998. This figure represents a 6.2% increase in sales over the previous year, and the number of units sold reached 1.83 billion. The frozen TV dinner was introduced in North America about half a century ago and since then has gone through various modifications. But, the overall concept of introducing a high quality, convenient meal for a reasonable value is still in demand. Today, the term home meal replacement (HMR) is often used to describe the concept of providing the consumer with an easy to prepare, convenient, fast meal. Some of the HMR products include presliced and marinated chicken breasts, oven-crisp chicken breast chunks and chicken tenders packaged in resealable plastic bags with serving suggestions. All are designed to allow the consumer to prepare a meal within 10 to 12 minutes. An example of chicken cacciatore with fettuccini is provided in Figure 1.13. This product exemplifies a convenient entree that can be prepared within 7 minutes in a microwave oven, as well as a meal appealing to the nutrition-conscious consumer. Clearly marked on the main product's package is the fact that the product can be prepared in a microwave (shown by a logo of a microwave oven), that the product contains less than 300 calories (of which only 10% are from fat) and that the product is also a source of fiber. Figure 1.13 also shows suggested cooking recommendations, an ingredients list and detailed nutritional information. In addition, the manufacturer provides a toll-free number for consumers' questions and concerns as part of the overall image of a "high quality product you can count on." It should be mentioned that nutritional information such as provided for this product is not mandatory in most countries but is included to attract a certain segment of the population. Such a product represents the high end of this category, which is designed to attract health conscious consumers who are also looking for a fiber source. Other products, such as a fried chicken entree, described on the package as "seasoned boneless chicken with potatoes, corn and apple-cranberry dessert" do not necessarily show the calorie content (e.g., 420 for a 290 g meal) on the package. As one industry person has said, this is a tough category because these meals compete not only with everything in the frozen category, but also with every other food option available out there, such as fast food, deli, sandwich shops and restaurants. Another segment of the convenient-food industry is refrigerated lunch kits. In the United States, this category reached sales of 0.64 billion in 1998 with about 333 million units sold. This represented an increase of 14.5% in actual dollars and 12% in the number of units sold over the previous year. The tremendous increase in HMR is related to the fact that recent surveys in North America have shown that over two-thirds of adults do not know in the morning what they are going to eat for dinner. This number is reduced to about one-quarter by 4:00 pm. This obviously will continue to present a big opportunity for the food industry, where people strapped for time are interested in finding quick meal solutions, such as semi/fully cooked poultry products, salad mixes, shredded cheese, etc.

MICROWAVEABLE

5 minutes

CHICKEN CACCIATORE

with fettuccine

Tender chicken pieces in tomato sauce with red peppers, mushrooms and onions served over fettuccine pasta.

UNDER 300 CALORIES -- A SOURCE OF FIBRE

ONLY 10% CALORIES FROM FAT

PREPARATION INSTRUCTIONS:

Microwave (700 Watts): Lift corners of film to let steam escape. Microwave on high for 4.5-5 minutes, turning tray once. Let stand for 1 minute before serving.

Oven: Preheat oven to 375°F (190°C). Lift corners of film to let steam escape. Place tray on a baking sheet on middle rack of oven and heat for 25-30 minutes. Ovens may vary in rate of heating. Times given are approximate.

NUTRITION INFORMATION

per 1 tray serving (290 g)

ENERGY: 220 Cal; **PROTEIN: 22** g; **TOTAL FAT: 2.3** g (10% CALORIES FROM FAT); POLYUNSATURATES: 0.6 g; MONOUNSATURATES: 0.8 g; SATURATES: 0.7 g; CHOLESTEROL: 27 mg; **TOTAL CARBOHYDRATE: 27** g; SUGARS: 6.8 g; STARCH (COMPLEX CARBOHYDRATES): 17 g; DIETARY FIBRE: 3.3 g; **SODIUM: 730** mg; **POTASSIUM: 620** mg.

KEEP FROZEN UNTIL READY TO USE.
DO NOT USE IN TOASTER OVEN.
PROMPTLY REFRIGERATE ANY UNUSED PORTION.
DO NOT REHEAT TRAY.

INGREDIENTS: WATER, SEASONED CHICKEN (BREAST FILLETS, WATER, SALT), PASTA, TOMATOES (CONTAIN TOMATO JUICE, SALT, CALCIUM CHLORIDE, CITRIC ACID), RED PEPPERS, MUSHROOMS, ONIONS, CHICKEN EXTRACT, TOMATO PASTE, MODIFIED CORN STARCH, BROWN SUGAR, GARLIC, CHICKEN FAT, CONCENTRATED LEMON JUICE, SPICES, SALT.

☎ **QUESTIONS OR COMMENTS, PLEASE CALL TOLL FREE (800) 123-4567**

Figure 1.13. *Information Presented on a Chicken Entree Package.*

Another interesting trend worth mentioning is the increased consumption of specially raised poultry such as the French Label Rouge. Figure 1.14 shows the percent increased consumption of these free-range chickens. The Label Rouge concept (see below) was introduced in 1965 in France and, in 1998, it captured about 30% of the market with about 97 million broilers (Laszczyk-Legendre, 1999). Currently, Label Rouge broiler production represents about 10% of the total volume of French poultry production and 16% of the chickens produced in France. During the beef BSE crisis in 1996, demand for Label Rouge poultry increased significantly, because consumers felt more confident buying meat produced by a certified organization that prides itself on having a third party auditor. Other key factors that attracted consumers were that the feed contained no animal proteins and that the third party certification process, which allows tracing the bird to a particular flock and farm, was in place.

The concept of Label Rouge traditional free-range poultry was created in the 1960s to promote a better quality product and was introduced to take the place of the traditional "Sunday chicken." The rearing specifications included the following factors: the birds should be from a special slow-growing breed; the birds should have access to an open air environment; the usable area of the poultry house, at any single production site, should not exceed 1,600 m^2; the stocking density is limited to 12 birds (maximum 25 kg) per m^2; the feed formula contains at least 75% cereals, with no animal products; the marketing age is at least 90 days; and transportation from the farm to the slaughterhouse should be no more than 2 hours or 100 km. It should be noted that these specifications are also part of the European Union specification 1538-91 for traditional free-range poultry.

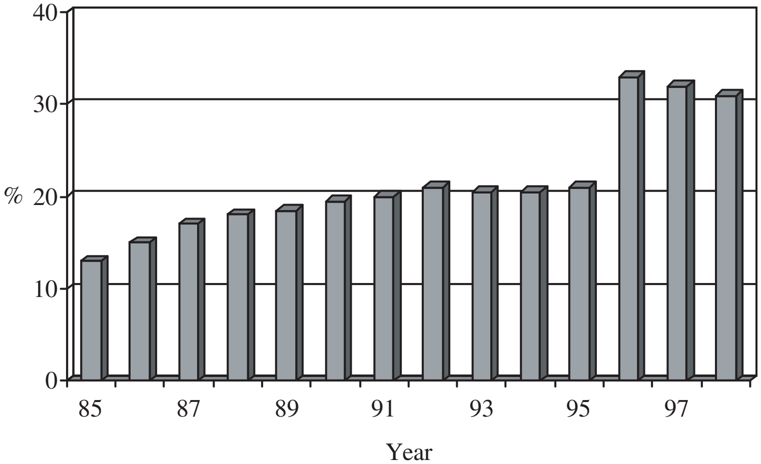

Figure 1.14. Increase in Label Rouge Poultry Consumption in France. Adapted from Laszczyk-Legendre (1999).

The Label Rouge logo is a trademark owned by the French Ministry of Agriculture and is conceded to certify an organization recognized for higher quality food products. Laszczyk-Legendre (1999) has indicated that "the capacity of the national organization to constantly adapt the product, method of production and certification system has brought Label Rouge poultry to a top quality level and transformed this avant garde concept to one of the future." Because this book is focusing on further processing, it will only be said that other countries are taking note of this growing trend and, depending on consumer demand in other parts of the world, further increase might be seen.

EXPORT MARKETS

Demand for poultry meat is expected to sharply increase over the next decade (Figure 1.15), in which the projected demand for poultry meat is higher than for other food commodities including red meat. Developing countries are projected to exceed the average world demand growth in all major commodities except rice. The demand for poultry and red meat, vegetable oil and grain is expected to be sharply higher in the developing countries compared to the developed countries. This will obviously result in more global shipments of poultry from high producing areas to demanding markets. It is expected that the major players will be the United States, Brazil, the European Union and Thailand. Net importers will be countries such as the former Soviet Union, Japan and China (Table 1.13).

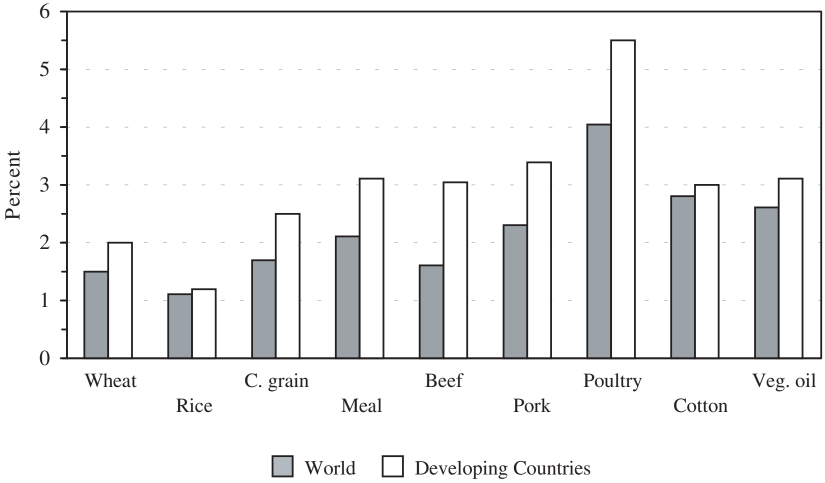

Figure 1.15. *Projected Annual Demand Growth, 1996–2007. From U.S. Department of Agriculture.*

Table 1.13. Statistical Trends for World Poultry Meat Trade. Reported in 1,000 Tons. From U.S. Department of Agriculture.

	1986	1996[a]	2006[b]
Exporting (net)	1,052	3,327	4,737
United States	257	2,052	3,058
Brazil	225	530	932
European Union	217	575	530
Thailand	65	165	161
Eastern Europe	288	5	56
Importing (net)	1,108	3,327	4,736
Saudi Arabia	180	290	341
Japan	174	533	764
Former Soviet Union	173	834	1,014
Hong Kong	89	213	284
Canada	30	35	40
Mexico	14	95	321
South Korea	—	42	154
China	28	300	672
Other countries	420	985	1,146

[a] Estimates.

[b] Projections.

Precise prediction of the world import/export market is difficult because many political and economical variables can be introduced without advanced notice. Incidences such as a major drought can result in higher feed prices in certain parts of the world and change the production cost equation (Figure 1.4) quite radically. Another example of a drastic change in the broiler's export market is shown in Table 1.14. A sharp decline in export to the former Soviet Union was seen in 1998 by United States exporters when political problems and devaluation of the Russian ruble occurred. This also had a strong effect on the average price of certain broiler meat portions (Table 1.14). The prices indicated show the average value per ton but do not include a description of the meat shipped. Overall, meat shipped to the former Soviet Union included less expensive cuts (leg meat, mechanically deboned meat), compared to higher valued meat cuts (e.g., chicken breast filets, whole birds) shipped to Western Europe, the Middle East and South America.

Overall, the material presented in this chapter indicates that an increase in the world's population and higher per capita consumption of poultry meat are expected to increase over the next few decades. This represents an excellent opportunity for the poultry industry to grow and improve. The material in the following chapters will hopefully be of value to industry personnel, students,

Table 1.14. U.S. Exports of Broiler Meat to World Regions. Summary from Thornton (1999). Based on U.S. Department of Agriculture Data.

		Value in Million Dollars		Change 1997 to 1998		Volume in Metric Tons		Average $ Per Metric Ton
	Region	1997	1998	Million Dollars	%	1997	1998	
1	Former Soviet Union	858,232	669,841	−188.4	−22	1,093,313	937,711	714
2	Asia	509,235	481,211	−28	−5.5	581,941	628,936	765
3	North America	252,635	266,435	13.8	5.5	166,799	185,477	1,436
4	Caribbean	81,486	91,774	10.3	12.6	74,915	90,488	1,014
5	Eastern Europe	48,915	62,356	13.4	27.5	66,557	84,946	734
6	Middle East	24,034	31,279	7.2	30.1	17,464	31,180	1,003
7	Africa	32,846	27,223	−5.6	−17.1	42,287	38,883	700
8	South America	16,696	23,290	6.6	39.5	18,310	29,958	777
9	Oceania	17,072	22,683	5.6	32.9	11,653	22,096	1,027
10	European Union	21,606	20,114	−1.5	−6.9	29,871	48,720	413
11	Central America	11,039	17,371	6.3	57.4	11,573	20,467	849
12	Other Western European countries	1,248	914	−0.3	−26.7	966	701	1,304
	Total	1,875,044	1,714,491	−160.5	−8.6	2,115,649	2,119,563	809

Table 1.15. Glossary. Source: French Meat Industry Center (2000).

English	French	German	Italian
Poultry	Volailles	Geflügel	Aves
Hens	Poulet	Hähnchen	Pollo
Cock	Coq	Hahn	Gallo
Turkey	Dinde	Pute	Pavo
Goose	Oie	Gans	Oca
Duck	Canard	Ente	Patos
Quail	Caille	Wachtel	Codorniz
Partridge	Perdrix	Rebhuhn	Perdriz
Feather game	Gibier a plume	Federwild	Caza con pluma
Cuts	Découpes	Teilstücke	Despieces
Giblets	Abats	Innereien	Menudillos
Leg	Cuisse	Schenkel	Muslo
Drumstick	Pilon	Schenkeule	Pata
Wing	Aile	Flügel	Ala
Breast	Blanc	Brust	Pechuga
Meat	Viande	Fleisch	Carne
Neck	Cou	Hals	Cuello
Tail	Croupion	Bürzel	Rabadilla
Skin	Peau	Haut	Piel
Liver	Foie	Geflügelleber	Higadillos
Heart	Cour	Herz	Corazón
Gizzard	Gesier	Kaumagen	Molleja

equipment manufacturers, ingredient suppliers, government personnel and consumers interested in obtaining information about further processing of poultry. In addition, to assist the reader in this international field, a table converting different poultry terms to four languages is provided in Table 1.15.

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CHAPTER 2

Basic Anatomy and Muscle Biology

INTRODUCTION

THE anatomical structure of the major meat-producing poultry and the four major tissues composing the carcass (i.e., muscle, epithelial, nervous and connective tissues) will be described in this chapter. Greater emphasis will be given to the muscle tissue component, because it represents the major edible part important to processors and consumers.

The mechanism of muscle contraction is also described as a basis for understanding post-slaughter changes (e.g., onset of rigor mortis, pH decline) that are known to affect meat quality. The biochemical differences between red and white muscle fibers related to quality attributes of the so-called white and dark poultry meat are highlighted. Overall, this chapter serves as an introduction to the structure of poultry and to meat science as they relate to meat quality.

STRUCTURE OF MEAT-PRODUCING POULTRY

Figure 2.1 shows the overall structure of a chicken, which is fairly typical of avian species; the proportion and size of certain body parts vary depending on a specific bird's living environment. In the case of a chicken, the legs are fairly developed because chickens usually live in open spaces and forests where walking and standing represent a major activity. The wings are fairly developed in the wild ancestors of the domesticated chicken and serve for fast escaping from predators and relatively short flights. The breast muscles that support the wings are also fairly developed. However, today's meat-type birds are selected for heavy musculature, especially breast muscles, and are much heavier than their ancestors. A more extreme case is the domesticated turkey (Figure 2.2) which, due to intense selection for heavy musculature, is an almost flightless bird. The legs and toes are structured to allow walking and perching on branches in the case of chickens and turkeys. In the case of ducks (Figure 2.3), the feet are adapted to swimming and have webbing between the

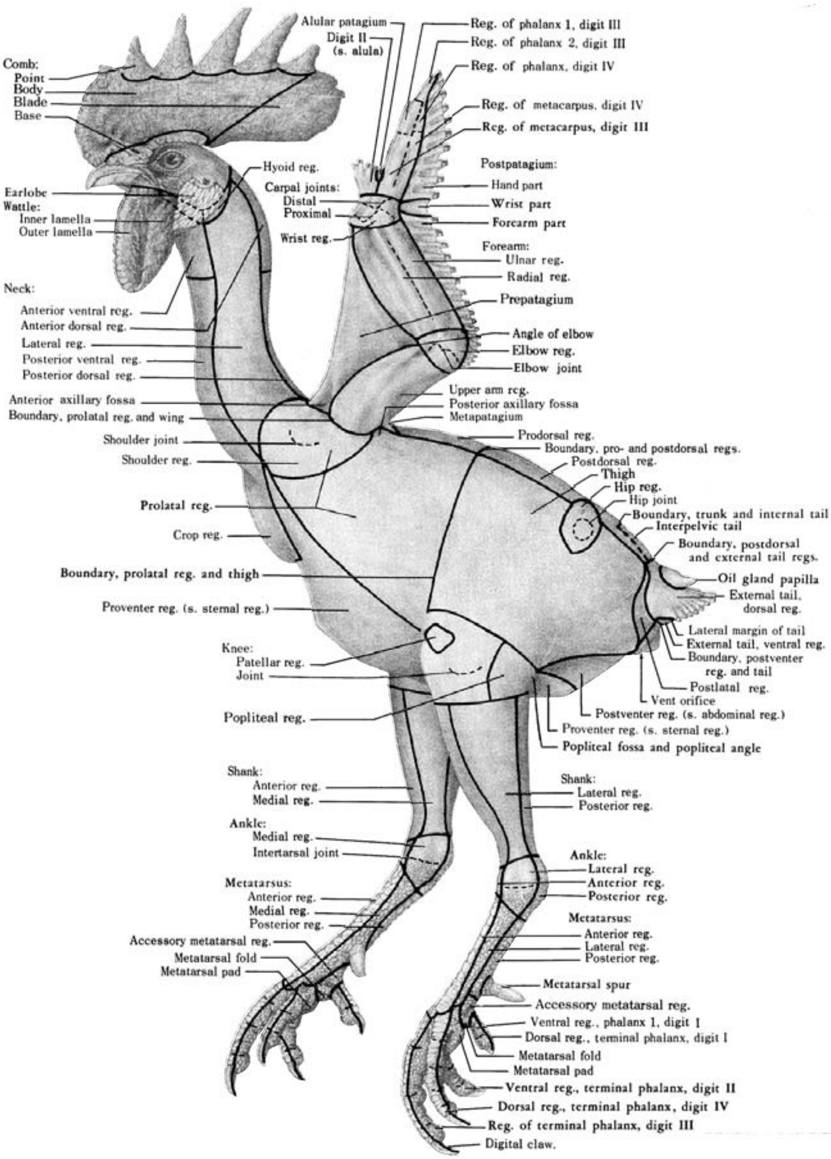

Figure 2.1. *Left Lateral View of the Chicken Showing the Different Regions. Abbreviations: Reg(s)., Region(s); s., Synonym. From Lucas and Stettenhiem (1972).*

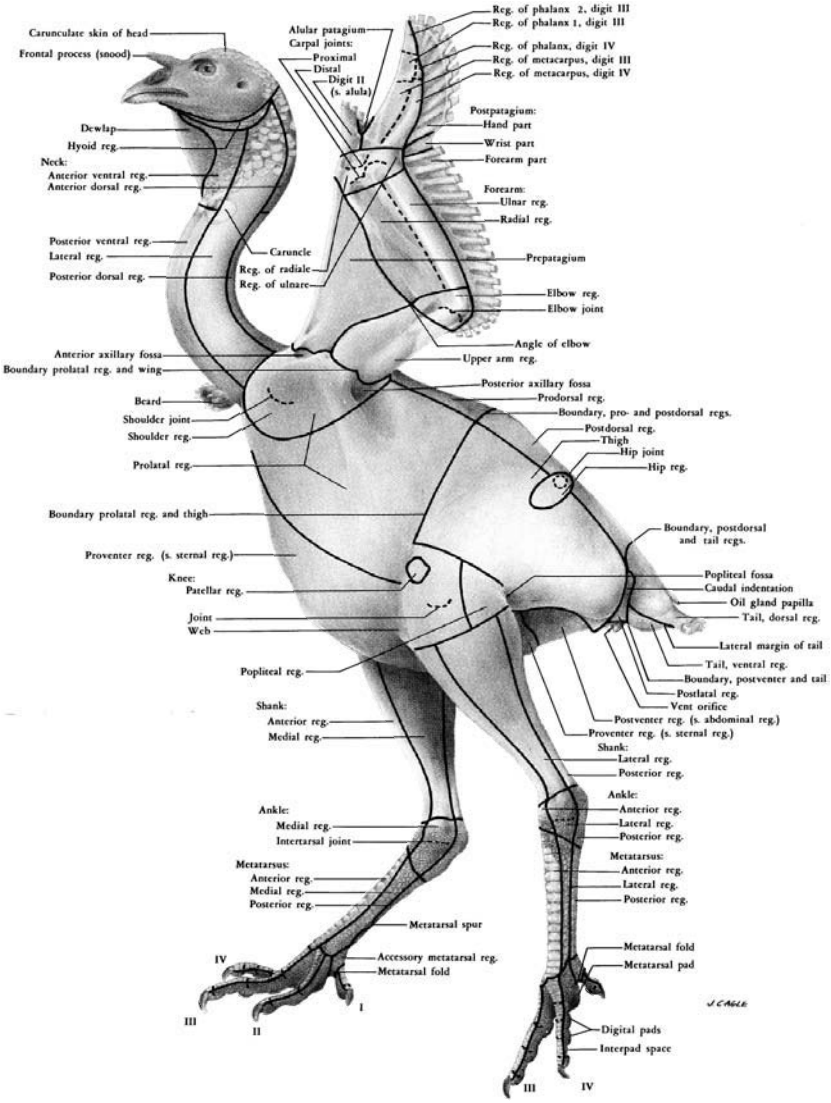

Figure 2.2. *Lateral View of a Turkey Showing the Different Regions. Abbreviations: Reg(s)., Region(s); s., Synonym. From Lucas and Stettenhiem (1972).*

toes, which serves as paddles during swimming. The feet are relatively short compared to turkey feet. The beak has also evolved to fit a marsh-type environment where a wider beak allows for the straining of water and for catching small fish and frogs. In the case of the pigeon (Figure 2.4), large wings in relation to the body size are used for long distance flying and gliding. The

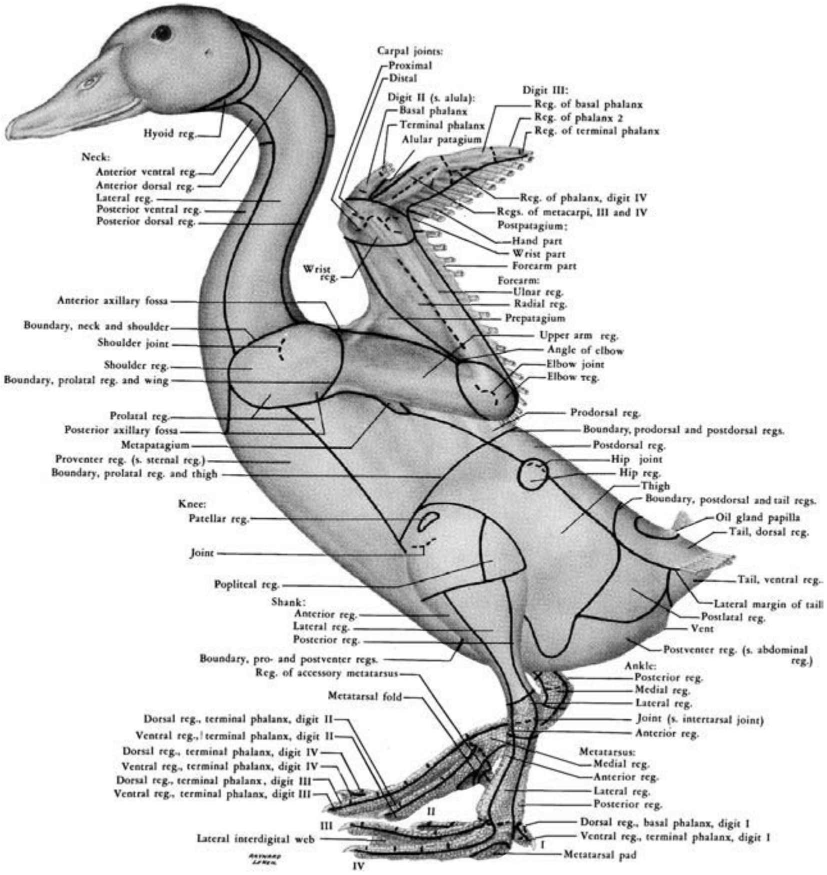

Figure 2.3. *Lateral View of the White Peking Duck Showing the Different Regions. Abbreviations: mar., Margin; Reg(s)., Region(s); s., Synonym. From Lucas and Stettenhiem (1972).*

overall structure of the wing bones resembles the basic structure found in mammals; however, major evolutionary modifications have occurred to allow the bird to fly.

MUSCLE TISSUE

Muscle tissue is considered most important in terms of poultry meat further processing and will be described in detail below. The so-called white and dark muscle/meat in chickens and turkeys (i.e., the most commonly consumed poultry; see Chapter 1) represents the major edible parts of breast and

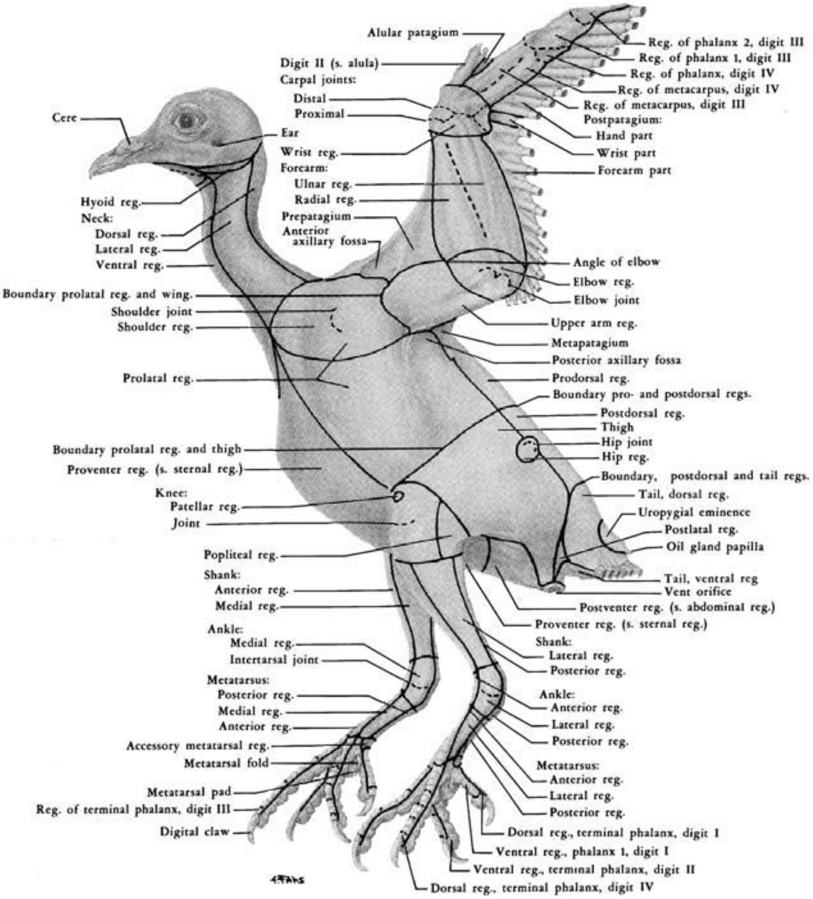

Figure 2.4. *Lateral View of the Common Pigeon Showing the Different Regions. Abbreviations: Reg(s)., Region(s); s., Synonym. From Lucas and Stettenhiem (1972).*

leg meat, respectively. However, in ducks, the breast meat appears red due to its high myoglobin content, as will be discussed later in the chapter. Regardless of bird type, a high yield of lean meat is sought by producers and processors.

In the live animal, muscles are used for various functions. The shape and structure of each muscle is designed to allow for the performance of a specific task. Muscle functions can range from locomotion (walking, flying) to pumping (heart muscle for circulating blood) and moving food along the guts by the involuntary muscles used in the digestive system. These three major activities are related to the three types of muscles found in the body: skeletal (movement), cardiac (pumping blood) and smooth muscle (involuntary activities).

Skeletal Muscle

The skeletal muscle is considered to be mostly a voluntary-type muscle, meaning that the animal has full or a certain degree of control over its activity. An overview of the major skeletal muscles in poultry is shown in Figure 2.5. The muscles range from very large muscles such as the breast muscle *(pectoralis major)* to very small muscles such as the ones controlling eye movement.

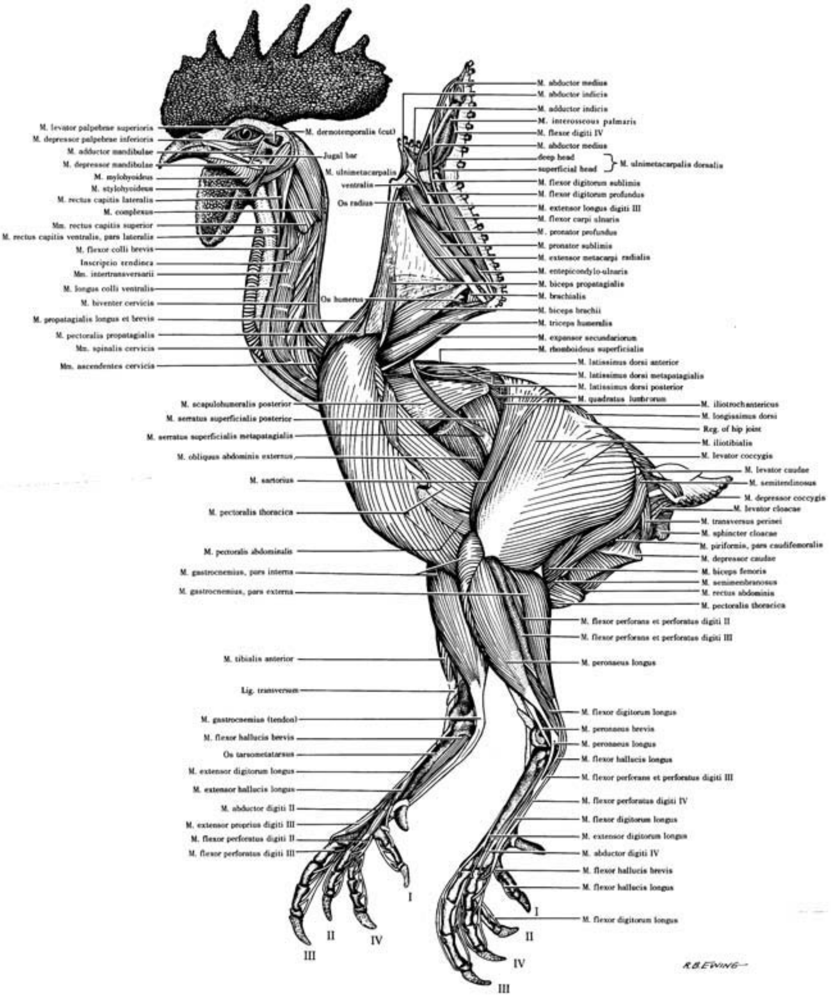
M. levator palpebrae superioris
M. depressor palpebrae inferioris
M. adductor mandibulae
M. depressor mandibulae
M. mylohyoideus
M. stylohyoideus
M. rectus capitis lateralis
M. complexus
Mm. rectus capitis superior
M. rectus capitis ventralis, pars lateralis
M. flexor colli brevis
Inscripcio tendinea
Mm. intertransversarii
M. longus colli ventralis
M. biventer cervicis
M. propatagialis longus et brevis
M. pectoralis propatagialis
Mm. spinalis cervicis
Mm. ascendentes cervicis
M. dermotemporalis (cut)
Jugal bar
M. ulnimetacarpalis
ventralis
Os radius
Os humerus
M. abductor medius
M. abductor indicis
M. adductor indicis
M. interosseous palmaris
M. flexor digiti IV
M. abductor medius
deep head
superficial head
M. ulnimetacarpalis dorsalis
M. flexor digitorum sublimis
M. flexor digitorum profundus
M. extensor longus digiti III
M. flexor carpi ulnaris
M. pronator profundus
M. pronator sublimis
M. extensor metacarpi radialis
M. entepicondylo-ulnaris
M. biceps propatagialis
M. brachialis
M. biceps brachii
M. triceps humeralis
M. expansor secundariorum
M. rhomboideus superficialis
M. latissimus dorsi anterior
M. latissimus dorsi metapatagialis
M. latissimus dorsi posterior
M. quadratus lumbrorum
M. scapulohumeralis posterior
M. serratus superficialis posterior
M. serratus superficialis metapatagialis
M. obliquus abdominis externus
M. sartorius
M. pectoralis thoracica
M. pectoralis abdominalis
M. gastrocnemius, pars interna
M. gastrocnemius, pars externa
M. iliotrochantericus
M. longissimus dorsi
Reg. of hip joint
M. iliotibialis
M. levator coccygis
M. levator caudae
M. semitendinosus
M. depressor coccygis
M. levator cloacae
M. transversus perinei
M. sphincter cloacae
M. piriformis, pars caudifemoralis
M. depressor caudae
M. biceps femoris
M. semimembranosus
M. rectus abdominis
M. pectoralis thoracica
M. flexor perforans et perforatus digiti II
M. flexor perforans et perforatus digiti III
M. peronaeus longus
M. tibialis anterior
Lig. transversum
M. gastrocnemius (tendon)
M. flexor hallucis brevis
Os tarsometatarsus
M. extensor digitorum longus
M. extensor hallucis longus
M. abductor digiti II
M. extensor proprius digiti III
M. flexor perforatus digiti II
M. flexor perforatus digiti III
M. flexor digitorum longus
M. peronaeus brevis
M. peronaeus longus
M. flexor hallucis longus
M. flexor perforans et perforatus digiti III
M. flexor perforatus digiti IV
M. flexor digitorum longus
M. extensor digitorum longus
M. abductor digiti IV
M. flexor hallucis brevis
M. flexor hallucis longus
M. flexor digitorum longus
I
II
IV
III
I
II
IV
III
R.B.EWING

Figure 2.5. *Lateral View of the Superficial Musculature of a Single Comb White Leghorn Chicken. Abbreviations: Lig., Ligamentum; M(m)., Musculus(i); Reg., Region. From Lucas and Stettenhiem (1972).*

The skeletal muscles are also known as striated muscles because of the striated appearance they possess when stained and viewed under a light microscope. This appearance is the result of repetitive microstructure of the fibers and their components.

Figure 2.6 shows a schematic diagram of the muscle structure and its components. A large muscle such as the *biceps femoris* is composed of numerous

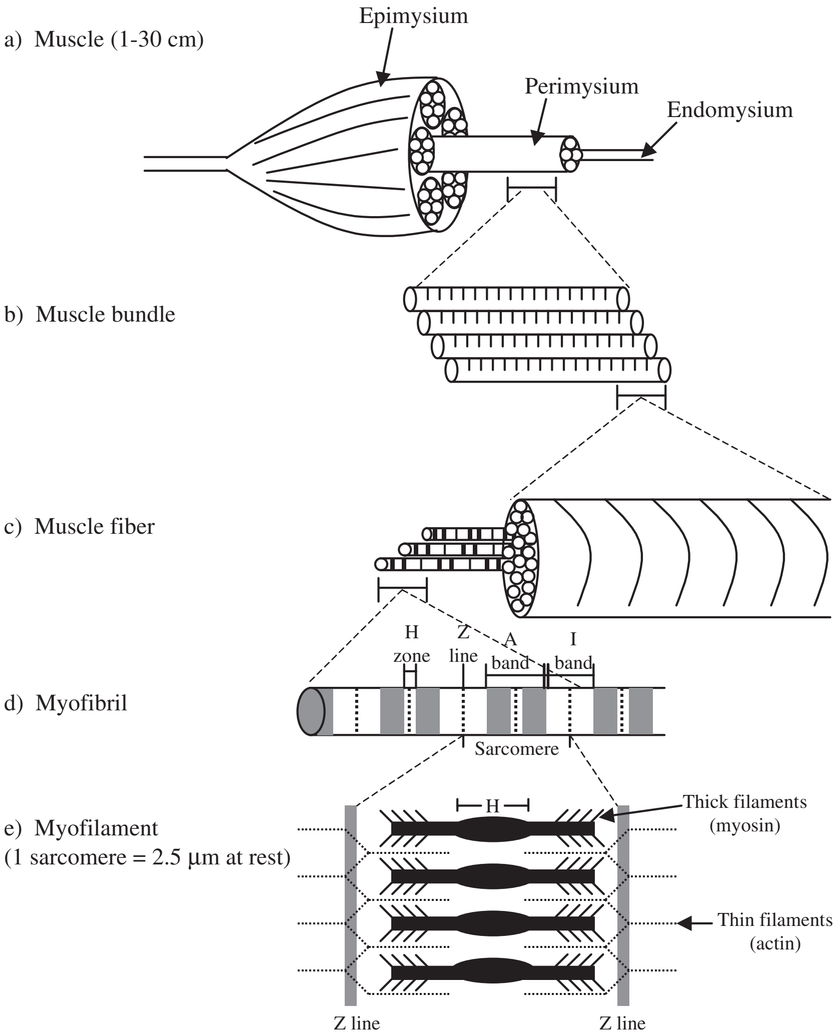

Figure 2.6. *Schematic Diagram Showing the Muscle Structure, Starting from a Cross Section of a Whole Muscle (a), Including the Different Layers of Connective Tissue, Going Down to the Muscle Bundle (b), Fiber (c), Myofibril (d) and Myofilaments (e). Please Note the Scale (1 meter = 100 centimeters = 1,000 millimeters = 10^6 microns = 10^9 nanometers = 10^{10} angstroms).*

muscle bundles covered by *epimysium* [Figure 2.6(a)]. Each muscle bundle [Figure 2.6(b)] is separated from the others by a connective tissue called *perimysium*. The connective tissue is important in providing structural organization, anchoring the different components and transmitting the power generated by contraction of the small muscle units called the sarcomeres. (Note: additional discussion on the various types of connective tissue is found later in the chapter.) Blood vessels are also seen in a cross section of the muscle, as well as groups of nerves that are reaching the muscle fibers and controlling their contraction. The individual nerves are usually not visible by the naked eye, but some large white/silvery nerve trunks can be seen. The muscle bundle is composed of smaller muscle fibers [Figure 2.6(c)] that are covered by a thinner layer of connective tissue called *endomysium*. Each fiber consists of numerous myofibrils [Figure 2.6(d)] that have myofilaments inside of them. The myofibril's striated appearance is the result of the repetitive structure of overlapping thin and thick filaments. The dark area in a stained muscle preparation [Figure 2.6(d)] is the result of thin and thick filaments overlapping and is called the A-band. The A-band also consists of an area where no thin filaments are present and, therefore, it is slightly lighter and is called the H-zone [Figure 2.6(e)]. During muscle contraction, the thick filaments slide toward the Z-line and, by doing so, shorten the overall length of the sarcomere and cause movement; a detailed discussion on muscle contraction is found below.

Cardiac Muscle

The cardiac muscle cell has a striated appearance like a skeletal muscle, but it has one (and sometimes two) nucleus per cell, whereas a striated muscle cell has numerous nuclei (Figure 2.7). The average length of the cell is

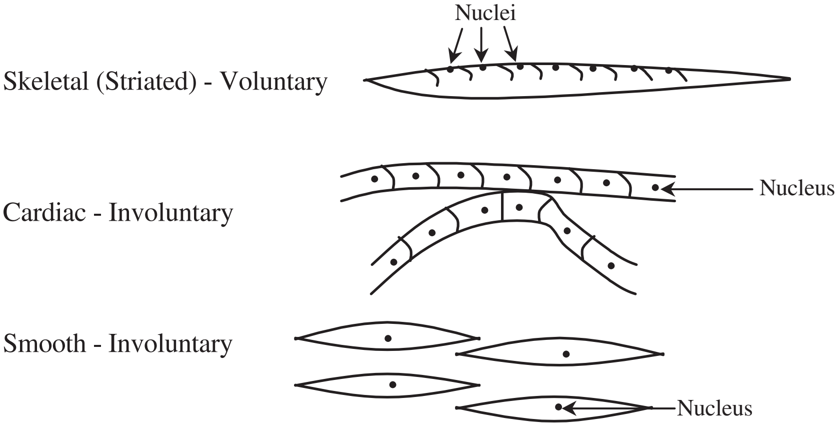

Figure 2.7. *Skeletal (Single Cell), Cardiac and Smooth Muscle Cells.*

about 50–100 μm, and its width is about 15 μm. The cardiac muscle has a unique rhythmic contraction that starts from the early embryonic stage and is triggered from the sinuatrial node. Another unique structural characteristic is that the fibers run in a mesh-like pattern and are branched. This allows the heart chambers to contract, reduce their volume and pump the blood forward.

Microscopic examination reveals unique structures called the intercalated disks that appear as dense lines at regular intervals along the longitudinal axis of the fiber. The disks provide a cohesive link between the heart muscle fibers and facilitate the transmission of contraction force from one fiber to the other. The heart is controlled by the sympathetic and parasympathetic nervous systems that are partly outside the central nervous system. The heart muscle is very active and has an extensive blood supply that results in its dark red color.

Smooth Muscle

The smooth muscle has relatively long and narrow cells with an average length of a few hundred μm and a diameter of 3–12 μm. The fibers have a single nuclei that is usually centrally located (Figure 2.7). The smooth muscle cells are associated with the involuntary systems in the body (e.g., digestive system, walls of arteries and parts of the reproductive system). The reason the muscle does not show a striated appearance is that the repetitive structure of the sarcomeres is not as well organized as in the skeletal and cardiac muscle fibers; thus, it is called a smooth muscle. In certain locations, such as the digestive system, a cross section reveals different layers of smooth muscle sheaths. Some of the sheaths are perpendicular, whereas others are parallel to the cut surface. This allows the muscles to decrease the diameter of the gut as well as elongate/contract its length. By performing this double action, the gut system can move food forward.

MUSCLE PROTEINS

Proteins represent essential building blocks of the muscle structure. The proteins consist of about 18–20% of the lean muscle weight, where water and fat represent about 75% and 5%, respectively. The muscle proteins can be divided into three major groups (Table 2.1) based on their water and salt solubility (Asghar et al., 1985). A common procedure used in a muscle biology laboratory to separate the muscle proteins is to homogenize a piece of lean muscle tissue (e.g., 1:1 meat to water) in a high speed mixer/homogenizer. Then, the homogenate is placed in a test tube and centrifuged to separate the aqueous phase that contains the water-soluble proteins, also called the sarcoplasmic proteins. After decanting the upper layer, a salt solution (e.g., 0.6 M NaCl or KCl) is added to the bottom layer, mixed well (or homogenized) and centrifuged. This

Table 2.1. The Major Proteins in an Average Lean Avian Muscle Divided into Three Groups According to Their Solubility (See Text) and Their Relative Percentage in the Wet Muscle (Based on 19% Total Protein).

Group	Protein	
Sarcoplasmic		(5.5)
	Myoglobin	0.2
	Hemoglobin	0.6
	Cytochromes	0.2
	Glycolytic enzymes	2.2
	Creatine kinase	0.5
Myofibrillar		(11.5)
	Myosin	5.5
	Actin	2.5
	Tropomyosin	0.6
	Troponin	0.6
	C-Protein	0.3
	α-Actinin	0.3
	β-Actinin	0.3
Stromal		(2.0)
	Collagen	1.0
	Elastin	0.05
	Mitochondrial	0.95

separates the salt-soluble proteins, called myofibrillar proteins, and the bottom layer of the nonsoluble proteins, called the stromal proteins.

Sarcoplasmic proteins are water soluble and are distributed within the cellular fluid (sarcoplasm). The liquid in which they are found after separation appears red because it contains the oxygen-carrying molecule, myoglobin (see structure in Chapter 13), and various enzymes (Table 2.1). The sarcoplasmic proteins consist of about 25% of the muscle's proteins.

Myofibrillar proteins, also known as the contractile or cytoskeletal proteins, consist of about 55% of the total proteins. This group of proteins makes up the thick and thin filaments (Figure 2.6) that are mainly made of myosin and actin, respectively. Additional discussion on the structure of myosin and actin, as well as their functions, is provided below.

Stromal proteins are the water- and salt-insoluble proteins consisting of about 10–15% of the muscle's proteins, mainly including the connective tissue proteins. The two major proteins are collagen and elastin. In the living muscle, they form various structural components including membranes surrounding cells, muscle bundles (*perimysium;* Figure 2.6), muscles *(epimysium),* ligaments and tendons, and they are found within joints as intermittent material. Overall, collagen is the most abundant protein in the animal's body (i.e., considering the entire body mass that includes bones, cartilage, etc.). The

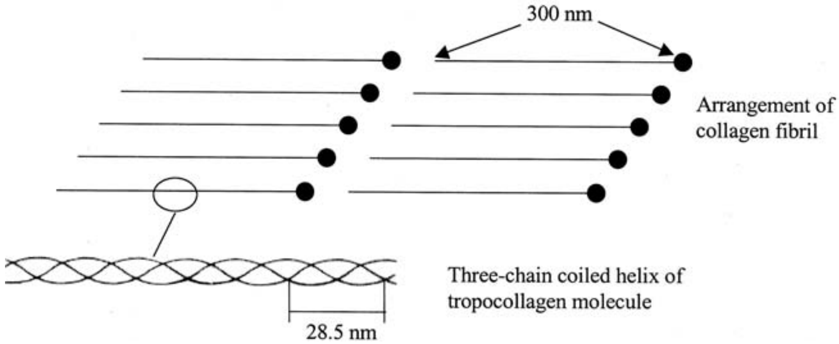
300 nm
Arrangement of collagen fibril
Three-chain coiled helix of tropocollagen molecule
28.5 nm

Figure 2.8. *Microstructure of a Collagen Fibril that Shows How the Fibril, Participating in Muscle Movement, Can Stretch. A Striation Pattern Is Seen at 64–67 nm Intervals Due to the Parallel Layout of the Tropocollagen Molecules. The Striation Can Be Seen after Negatively Staining a Sample with Heavy Metals and Viewing with an Electron Microscope.*

connective tissue sheaths surrounding muscles, muscle bundles and muscle fibers are known as "connective tissue proper." Cartilage and ligaments are known as the "supportive connective tissue" because they provide the body with support and structure. Collagen (Figure 2.8) is the main structural protein of the connective tissue. Its quantity varies among muscles, depending on the muscle's physical activity. Leg muscles, for example, have higher collagen because they are more active and are used to support the whole body. This higher amount of connective tissue makes leg meat tougher compared to less active muscles. See additional discussion regarding collagen structure and function later in the chapter.

MUSCLE CONTRACTION

The phenomenon we observe as movement is the result of muscle contraction, which is actually a very complex chain of events. Overall, it is the result of many sarcomeres (the smallest contracting unit) moving in harmony that produces tension, which is observed as a pulling in a certain part of the body. In the process, chemical energy, which is stored as a high-energy bond within the adenosine triphosphate (ATP) molecule, is converted into physical movement (Swatland, 1994). The following section will briefly describe the major proteins involved in muscle contraction, their unique structure and three-dimensional arrangement.

Myosin forms the thick filaments in the muscle and constitutes about 45% of the myofibrillar proteins. It is an elongated rod-shaped protein [Figure 2.9(a)] with a high molecular weight of around 450,000 daltons. It is composed of two

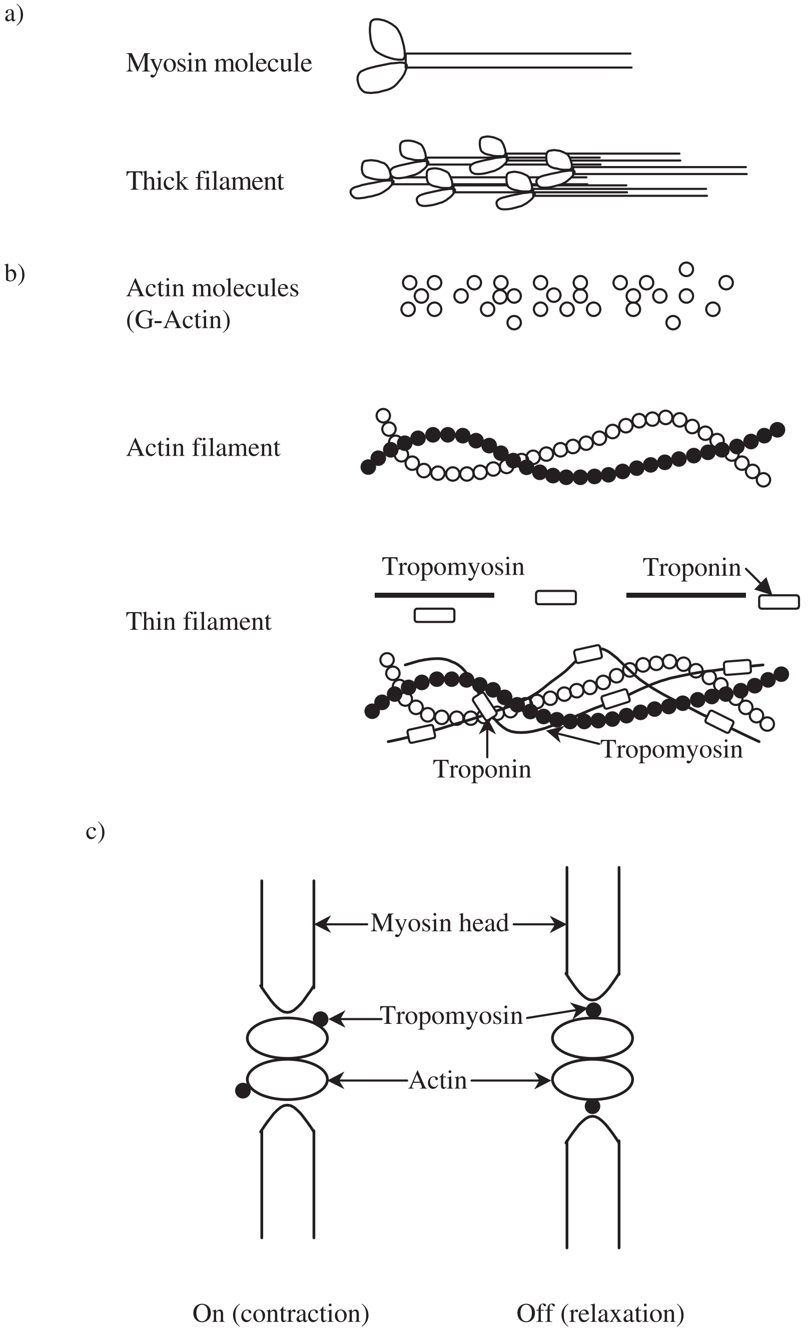

Figure 2.9. *The Microstructure of the Major Proteins Participating in Muscle Movement. Myosin that Builds the Thick Filaments (a); Actin, Troponin and Tropomyosin that Make Up the Thin Filament (b); and a Cross Section of the Thick and Thin Filaments (c) during Rest (Off) and during Contact (On).*

heavy and two light chains, that can be separated when myosin is subjected to a specific proteolytic enzyme activity. The heavy chains consist of the myosin's heads that are unique in their ability to split the ATP molecule into adenosine diphosphate and phosphate ($ADP + PO_4$). During movement, the heads form cross bridges with the actin molecules, using energy to change their orientation (i.e., bend), and by that, generating movement.

Actin forms the thin filament and has a lower molecular weight of 42,000 daltons. It consists of two chains of G-actin that are formed from individual F-actin molecules [Figure 2.9(b)]. This process takes place at a specific salt concentration that favors the formation of the chain. The thin filament is made up of two chains twisted together forming the so-called double helix of actin molecules.

Tropomyosin is a rod-like protein that surrounds the actin helical structure and constitutes about 5% of the myofibrillar proteins. There is one tropomyosin molecule for every seven actin molecules [Figure 2.9(b)]. It lies alongside the actin molecule and is positioned in the groove of the helical structure of the actin double helix.

Troponin is a globular protein that constitutes about 5% of the myofibrillar proteins. It is also present in the groove between the two actin filaments, where it lies within the tropomyosin strands. The troponin units are positioned in a repetitive pattern along the actin filament [Figure 2.9(b)]. There are three types of troponin: troponin-C which binds Ca^{++}, troponin-I which inhibits ATP and troponin-T which binds tropomyosin.

Different explanations have been proposed to explain muscle contraction. The most acceptable explanation is the so-called sliding-filament theory. According to this theory, the thick myosin filaments are sliding in between the thin actin filaments toward the Z-lines [Figure 2.6(e)]. During this process, one can measure the depletion of the energy-rich molecule ATP into ADP. As mentioned earlier, the myosin heads have a site capable of splitting the ATP, and by that, releasing the energy needed to bend or twist the heads and pull the myosin molecule toward the Z-line (Figure 2.10).

The trigger for starting the contraction process comes from the brain and is transferred via the nervous system (Figure 2.11). The signal travels through the nerve by depolarizing the membrane and changing the inside electrical potential from about −80 mV to +20 mV. During rest, the nerve membrane actively pumps positive sodium ions out of the cell and maintains the potential difference between the inside and outside of the cell. When a message is passed through the cell (also called action potential), a fast reverse of the electrical potential is seen. The overall change in polarization is very fast and takes about 1 millisecond before the original base condition is restored. When the signal arrives to the nerve's ending (Figure 2.11; motor end plates), the message is transferred to the muscle by chemical means. *Acetylcholine* is released from the nerve ending and causes the muscle cell's membrane to depolarize. It should be mentioned that this chemical messenger is broken down

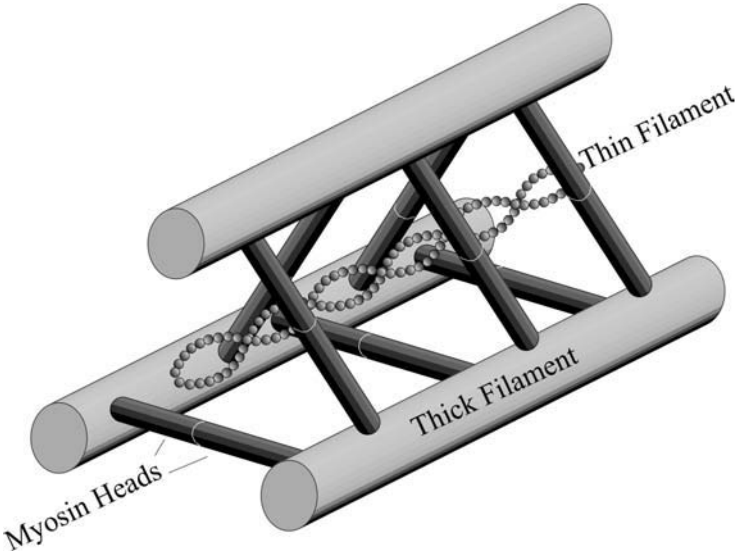

Figure 2.10. *Schematic Diagram of the Sliding Filament Theory. Adapted from Pollack (1990).*

very quickly (i.e., to prevent continuous signaling to the muscle) by an enzyme called *acetycholinesterase*. The chemical message is then causing an electrical depolarization in the muscle cell's membrane and is transferred to the myofibrils via a special arrangement of T-tubules within the sarcoplasmic reticulum. This triggers muscle contraction that consists of the following:

- calcium release from the sarcoplasmic reticulum's terminal cisternae into the sarcoplasm
- free calcium is quickly bound by troponin-C
- this, in turn, causes the tropomyosin to shift from the actin binding sites
- actin and myosin molecules form cross bridges [Figure 2.9(c)]
- the repeated formation and breaking of the cross bridges results in sliding of the thick filaments toward the Z-line and, hence, sarcomere shortening

During the relaxation phase, the signal coming from the nerve is stopped:

- the sarcolemma and the T-tubules are re-polarized, making them ready for the next signal
- the calcium pump, within the sarcoplasmic reticulum, is resequestering the calcium
- the actomyosin bridges are broken

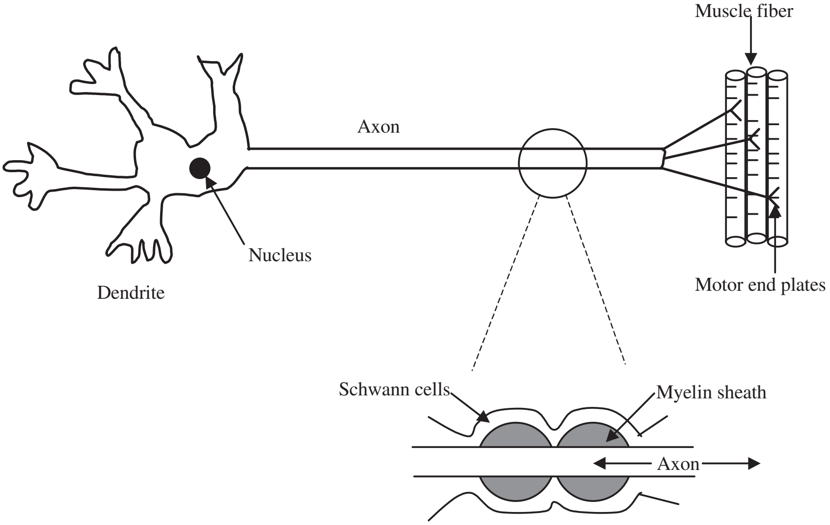

Figure 2.11. *A Schematic Drawing of a Neuron with Motor End Plates.*

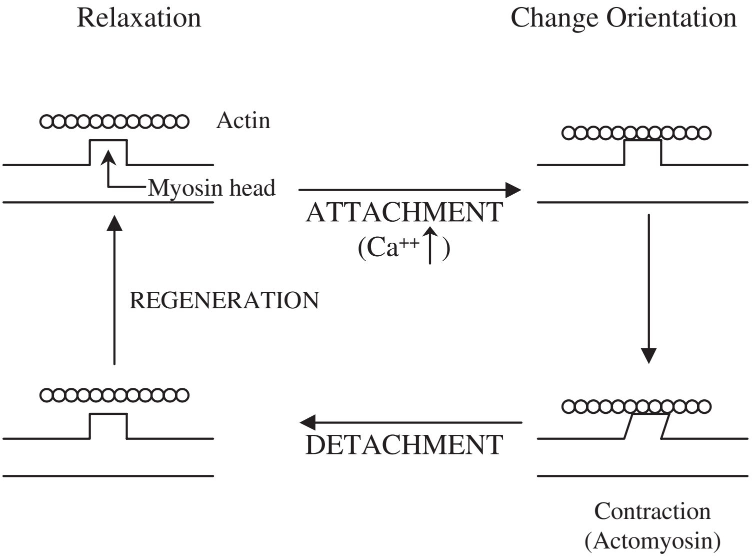

Figure 2.12. *A Schematic Illustration of the Steps Involved in Muscle Contraction.*

- the tropomyosin molecules return to the actin binding sites [Figure 2.9(c)]
- passive sliding of the filaments is observed, and the sarcomeres return to their resting state.

Calcium concentration in the sarcoplasm controls muscle contraction. During rest, the concentration of free calcium is below 10^{-8} mole/liter. When calcium is released, the concentration goes up to a level around 10^{-5} mole/liter. This causes the troponin-C to bind calcium which in turn triggers movement of the tropomyosin-troponin system away from the myosin binding sites on the actin molecules. During relaxation, free calcium is resequestered, and its concentration goes back to around 10^{-8} mole/liter.

A schematic illustration of the steps described above is provided in Figure 2.12 to assist the reader in understanding the sequence of events.

FIBER TYPE

In the poultry meat trade, there is a clear distinction between white and dark meat. White meat refers to the breast muscle from chicken and turkey, whereas dark meat refers to the leg meat. This classification is based on the overall color of the meat. In chicken and turkey, it can be said that this is also related to the relative proportion of red and white fibers within the muscle. Generally speaking, most muscles contain a mixture of red and white fibers; very few muscles are composed of all white or red fibers. The dark/red chicken/turkey meat has a high proportion of red fibers compared to white meat.

There are important metabolic and functional differences between red and white muscle fibers; some of the key ones are summarized in Table 2.2. It

Table 2.2. Relative Comparisons between Red and White Muscle Fibers in Poultry.

	Red Fiber	White Fiber
Myoglobin (concentration)	High	Low
Color	Red	White
Contraction speed	Slow	Fast
Mitochondria (number)	High	Low
Mitochondria (size)	Large	Small
Glycogen content	Low	High
Glycolytic activity	Low	High
Lipid content	High	Low
Oxidative metabolism	High	Low
Fiber diameter	Small	Large

should be pointed out that these differences are judged on a relative scale, and variation can exist within each characteristic. There is also an intermediate fiber type, not described here, that has intermediate characteristics. Overall, red muscle fibers have a higher myoglobin content (see myoglobin structure in Chapter 13) that results in a redder appearance. The red fibers contract more slowly but have the capacity to operate for a longer period of time (i.e., slower but sustained activity). The presence of a higher number and larger mitochondria than in white fibers, and the higher lipid content, allow the fibers to contract for a longer period of time. Muscles with a high proportion of red fibers are used to support the skeleton in an upright position and, because of their unique metabolism, are less easily fatigued. A good oxygen supply is important and, together with a high proportion of enzymes involved in oxidative metabolism (Table 2.2), the fibers can function for extended periods of time.

White fibers have less myoglobin and a lower oxidative enzyme activity than red fibers. The glycolytic metabolism, which predominates in the white fibers, can occur in either the presence or absence of oxygen, i.e., aerobic and anaerobic metabolism, respectively. Muscles dominated by white fibers show lower capillary density because they do not rely on fast nutrient transfer. Muscles with a high proportion of white fibers are known to contract more rapidly in shorter bursts (e.g., quickly flap the wings and lift a chicken off the ground) and are relatively easily fatigued. It should be mentioned that in some of the active wild-type birds, such as ducks and geese who fly far during their migration, the breast muscle appears fairly dark/red. This indicates that there is a higher proportion of red fibers, and the muscle can operate for extended periods of time.

From a marketing standpoint, the difference in muscle color can affect consumer acceptability and price in different markets. In North America, the price of white meat is much higher than dark meat. In some Far East regions, the situation is reversed, and dark poultry meat sells at a premium. Further discussion on meat quality and functionality is provided in the following chapters.

EPITHELIAL TISSUE

The main component of this tissue is the skin. The skin (Figure 2.13) serves as a protective layer that prevents microorganisms from entering the body and protects the body from environmental stresses such as drying. It also protects the body against mechanical damage and serves a major role in insulation and heat regulation. The two major parts of the skin are the epidermis, which is the ectodermal portion, and the dermis, which is the mesodermal portion (Figure 2.13). Poultry skin has pigmented cells that contain

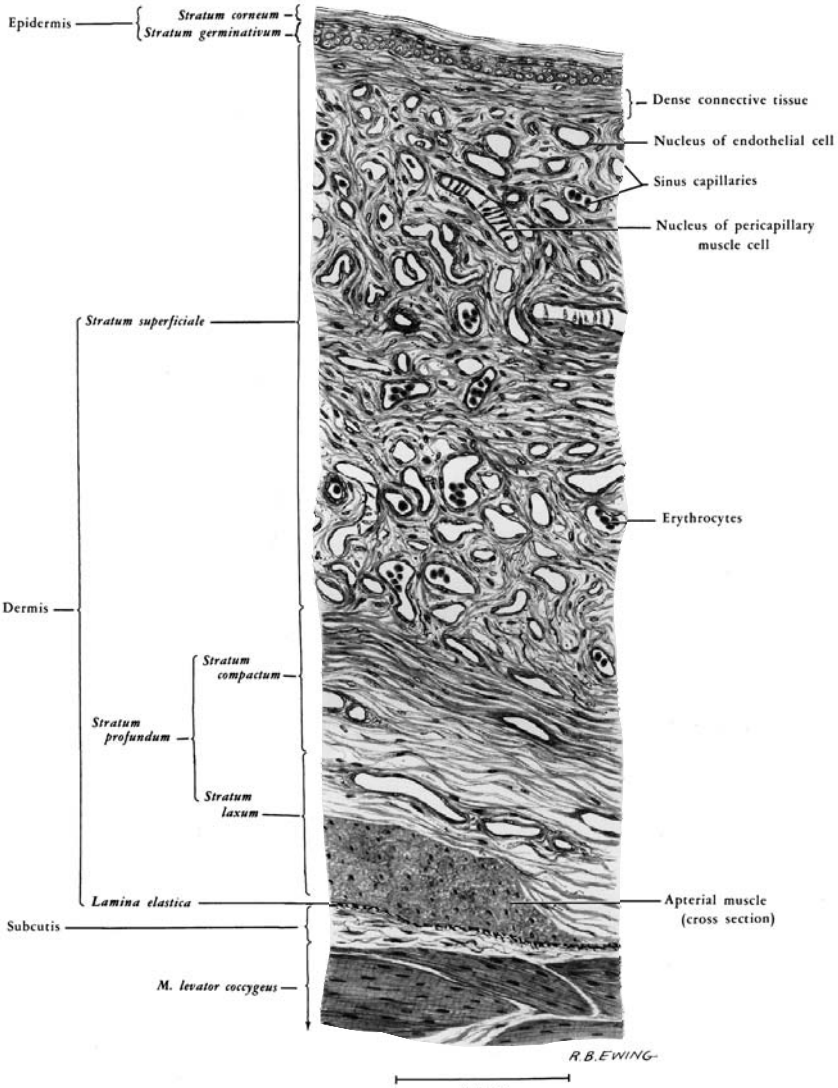

Figure 2.13. *Structure of a Mature Chicken Skin. Section Stained with Hematoxylin and Eosin. Abbreviation: M., Musculus. From Lucas and Stettenhiem (1972).*

melanin and, together with other plant pigments (e.g., xanthophyll, absorbed in the diet and can be deposited in the skin), give it a certain color (see discussion in Chapter 13). For the meat processor, the characteristics of the skin are important in terms of color (presentation), flavor and texture. The crispiness of fried chicken, for example, is due to the properties of the epithelial tissue and the underlying connective tissues. Other organs that contain epithelial tissue are the liver, kidney and the lining of the digestive system. The epithelial tissue is usually characterized by the shape of the cells and the number of layers forming it. The cells in the epithelial tissue are usually laid down with little extracellular material. The cell shape can vary from elongated columnar-type cells to very thin and flat cells called squamous cells. In addition, cuboidal cells also form single or multiple layers on external or internal surfaces of the body. In organs such as the liver and kidney, the cells secrete different enzymes, while in the digestive system, they absorb different nutrients from the gut. Of major importance in poultry are the feathers that are formed by epithelial tissue. Figure 2.14 shows the structure of a feather, and Figure 2.15 shows a cross section of a feather follicle. The feathers represent a complex derivative of the epithelial tissue. Size alone often has a very wide range, with the longest tail feathers of a roaster being about 1,000 times as long as the feathers on its eyelids. The predominant feathers on a bird's body

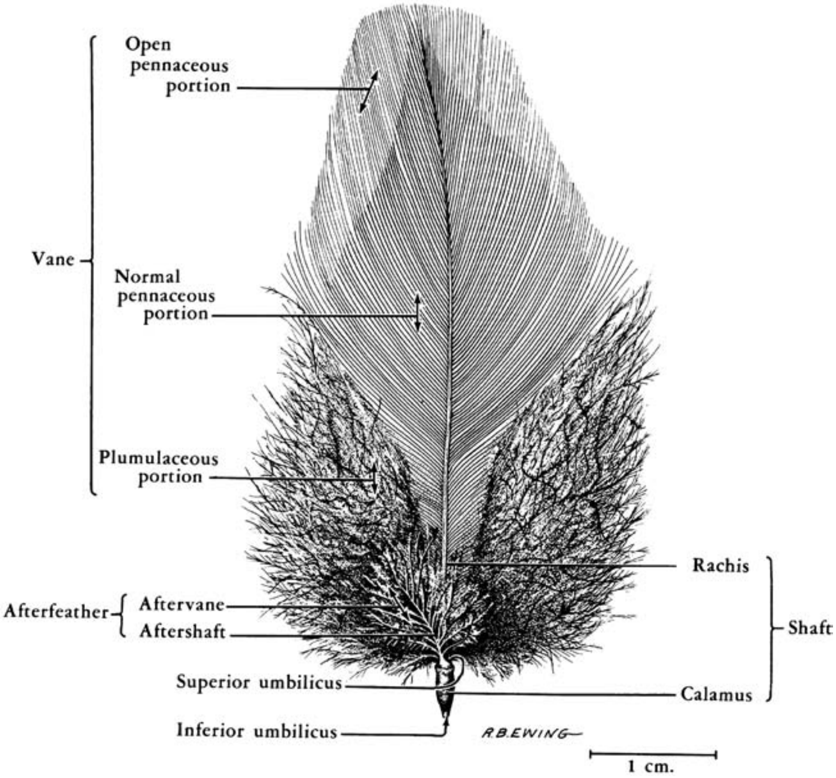

Figure 2.14. *A Structure of a Feather from the Middle of the Dorsal Tract of a White Leghorn Chicken. From Lucas and Stettenhiem (1972).*

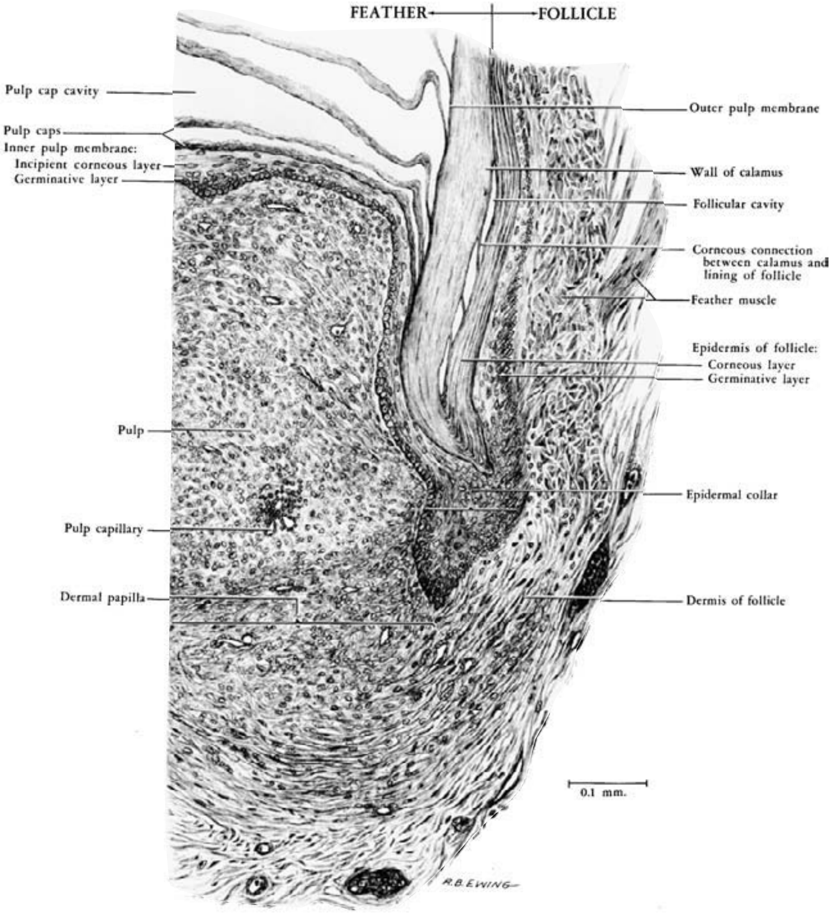

Figure 2.15. *A Longitudinal Microscopical Section through a Feather Follicle of a White Leghorn Chicken. From Lucas and Stettenhiem (1972).*

are called contour feathers and are composed of a shaft with the plates or vanes on either side (Figure 2.14).

The feather grows in a follicle (Figure 2.15). The follicle and its feather are both tubes of modified integument, showing a gradient from dermis to keratinized, highly flattened epidermis. The wall of the follicle appears to be drawn upward in some way by the sheath of the growing feather. The epidermis of the follicle, in a full-grown feather, has a single layer of germinative cells, which are low cuboidal cells and contain large nuclei (Lucas and Stettenheim, 1972).

NERVOUS TISSUE

The nervous system represents a small part of the edible meat, usually less than 1%. However, understanding its structure is important in explaining postmortem changes and meat quality issues. There are two main structural components. The first is the central nervous system that consists of the brain and the spinal cord. The second is the peripheral system that consists of the nerve cells that are part of the body. The nerve cell, or neuron (Figure 2.11), represents the basic structure of the nervous tissue. Neurons have a fairly distinct structure that consists of a cell body with an elongated fiber-type structure called axon. A nucleus is found within the polyhedrally shaped cell body. A few short branched structures called dendrites come out from the body. In a motor neuron, a long single axon branches when it reaches the muscle; the ends are called motor end plates (Figure 2.11). As can be seen in the figure, one nerve reaches a number of muscle fibers and triggers them all at the same time. The action potential that goes through the nerve (i.e., from the cell's body through the axon and the motor end plates) is transferred to the muscle or to other nerves (i.e., their dendrite portion) in an area called synapse. At this point, there is no physical connection of the two structures, but there is a small gap where in motor neurons a chemical messenger, called acetylcholine, is used to transfer the message to the muscle. (Note: within the brain and other locations, other chemical messengers are used.) Certain toxins can block acetylcholine and cause serious problems to an animal. One such toxin is produced by *Clostridium botulinum* and is associated with cases of food poisoning (see Chapter 11 for further discussion).

In the muscle, nerve trunks consisting of a group of axons can be observed as silvery lines. This trunk arrangement helps to protect the axons, which run parallel to each other, and provide strength to the structure. The peripheral nerve fibers are covered with Schwann cells and, in addition, the large fibers are covered with a myelin sheath (Figure 2.11). The small peripheral fibers do not have the myelin sheath and are only covered by Schwann cells. Therefore, nerve fibers are commonly referred to as myelinated and unmyelinated fibers. The position of the Schwann cells along the fiber assists in accelerating the movement of the action potential along the fiber.

CONNECTIVE TISSUE

The connective tissue is used, as the name implies, to connect and hold different parts of the body. It consists of bones, ligaments, tissue covering muscles, muscle bundles and fibers. As indicated before, the tissue responsible for building bones and cartilage is called "supportive connective tissue" because it provides structural support. The part that surrounds muscles, muscle bundles and fibers is called "connective tissue proper." The two types of connective tissue have many similarities in their composition and functionability. Usually, both consist of a few cells and a lot of extracellular substance. The substance can range from very soft to very tough material and contains embedded fibers that provide structure to the tissue. In bones, the extracellular substance is much tougher than in other locations and, in addition, contains calcium salts. In cartilage, the extracellular substance is more rubbery and soft. The unique structure of the collagen molecule provides strength and elasticity. Tropocollagen molecules are the basic structural units of the collagen fiber. They are composed of three α chains that form a triple helix (Figure 2.8). There are 12 types of collagen molecules that have different functional properties and, therefore, can be found in different locations. The different types of collagen result from at least 19 different α chains that can be combined in different ways to form a triple-chained coiled helix. During filament assembly, the tropocollagen molecules are aligned longitudinally, end to end, and laterally in a slightly overlapping stagger. This overlapping results in the unique striated appearance of the collagen fibers, which is different from the striation seen in skeletal muscle (Hedrick et al., 1994). It should be mentioned that not all types of collagen form fibers. Type I and III form large and fine fibers, respectively. Type IV collagen is non-fibrous and forms a chicken wire-like sheath that surrounds individual muscle fibers. In Type V and VIII collagen, the tropocollagen molecules are aligned longitudually and form microfilaments. In general, the number of collagen fibrils found at a certain muscle depends on the activity, load and stress that the muscle is expected to endure. Another factor that contributes to strength is the formation of intermolecular cross-linkages among the collagen fibrils. In young animals, there are less cross-linkages, and the ones present are easily broken. In an older animal, the number of cross-linkages increases, and the bonds are more difficult to break. Therefore, meat from an older animal is considered to be tougher.

The other major connective tissue protein, elastin (Table 2.1), has a different structure and possesses a much more rubbery texture (i.e., elastin fibers can be easily stretched, compared to collagen, and later return to their original length). Elastin is more commonly present in ligaments and arteries and provides the structure of certain organs.

The amount of connective tissue in a muscle/meat sample is usually assessed by the quantity of the imino acid hydroxyproline, which is unique to the collagen molecule structure. As indicated before, older animals are known to have tougher meat, but both processors and consumers should know that collagen can be broken down by exposure to heat. Therefore, prolonged moist heating is recommended for cooking tough cuts of meat, including spent hen meat. Heating results in breaking the cross bridges and eventually turning collagen into gelatin. The collagen becomes soluble during cooking (starting melting point ≈ 67°C) and, as exposure time and temperature increase, more will be converted to gelatin. After cooking, if the meat and its juices are left to cool, the juices will turn into a jello-like texture. Elastin, on the other hand, cannot be broken down by heat, and cuts of meat high in elastin should either be discarded or tenderized by mechanical means (e.g., small blades/needle tenderization; see Chapter 8).

Adipose tissue is also part of the connective tissue, and it consists mainly of cells and less extracellular fibers, as its main function is to store fat. The adipose tissue is usually found enclosed in areas surrounded by a sheath of collagen fibers. The young adipose cells are called adipoblast and, when they mature and fill with fat, are called adipocyte. The adipoblast grow from about 1–2 μm to a size of up to 100 μm, while accumulating small lipid droplets that later fuse to form a large fat globule. The development of the adipose tissue is related to age of the bird and the abundance/lack of nutrition. In young animals, the first fat deposit usually appears in the visceral area. Later, subcutaneous fat (under the skin) is developed, followed by a limited amount of intermuscular fat, which is deposited in between muscles. It should be mentioned that poultry is fairly unique, as compared to red meat animals, because intermuscular fat (or marbling) does not appear in most muscles (e.g., pectoralis). The adipose tissue represents an energy storage for the animal and is used in response to certain needs. Migrating birds, for example, can go through a large increase of their adipose tissue mass just before migration. In any case, the adipose tissue has a fairly dynamic metabolism, meaning that the lipids stored are constantly mobilized.

The bone structure in poultry is unique in its ability to provide great physical strength with relatively light weight. This is essential for the flying bird as opposed to the heavy bone structure found in red meat animals. The bone tissue consists of an organic matrix and inorganic salts. The first contains the collagen fibers and ground substance consisting of proteins and sugar complexes. The inorganic part is primarily made up of calcium and phosphate salts that form crystals deposited within the collagen fibers of the organic matrix. The structure consists of bone cells distributed within the matrix and arranged in small cylindrical elements called *lacuna*. These structures form a network of canals between the cell cavities, which is important in allowing for proper cell feeding. The structure of a long bone such as the humerus and femur is shown in Figure 2.16. The central shaft, called diaphysis, is hollow and filled with compact bone material. Both ends are enlarged to allow enough surface area for connecting with other bones (via cartilage-mediated medium) and are called epiphyses. The cartilage region separating the diaphysis and the epiphysis of the growing animal is called the epiphyseal plate and is the section responsible for elongating the bone. The central hollow part of the bone contains the bone marrow that produces new red blood cells. The bone

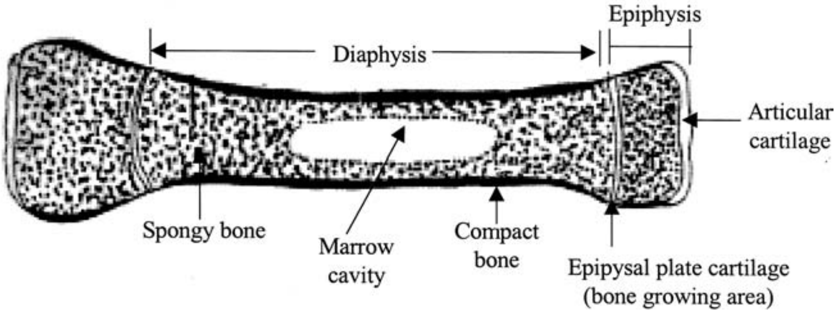

Figure 2.16. *The Structure of a Long Bone.*

represents a very dynamic system in terms of calcium deposition and withdrawal. It is interesting to note that the laying hen is used as a research model to study osteoporosis in humans because of the very fast calcium turnaround seen during the laying period. The overall skeletal structure of a chicken is shown in Figure 2.17. The figure shows a chicken skeleton, which is a fair representation of other birds; however, there are some differences between chickens, turkeys, quails, ducks and pigeons. It should be mentioned that the number of vertebrae of the axial skeleton varies among birds and also among individuals of the same species; the neck of a chicken can have 16 or 17 vertebrae (Lucas and Stettenheim, 1972).

Cartilage is part of the connective tissue used to connect and support different skeletal elements. The cells, called chondrocytes, are found in clusters located in small cavities within the extracellular material. The interlacing collagen form a delicate network of cartilage. Cartilage can differ in the relative amount of collagen fibers and extracellular material. This results in the formation of cartilage with different properties that can be divided into three main categories. The first is the hyaline cartilage found between individual vertebrae, on the surfaces of joints and bones and on the dorsal tips of vertebrae. The second type is the fibrocartilage found in tendons attaching bones and within ligaments of the joints. The fibrocartilage has numerous collagen fibers and can resist repetitive stress. The third type is the elastic collagen that consists of a number of branched elastin fibers that provide its elastic characteristics.

The blood and lymph systems are also part of the connective tissue system. The blood consists of a large portion of extracellular material in which various cellular components are suspended; the cell component usually represents about 40% of the blood volume. The red blood cells or erythrocytes transfer gases, such as oxygen, from the lungs to the body. The white blood cells, leukocytes, are part of the body's defense mechanism against infections.

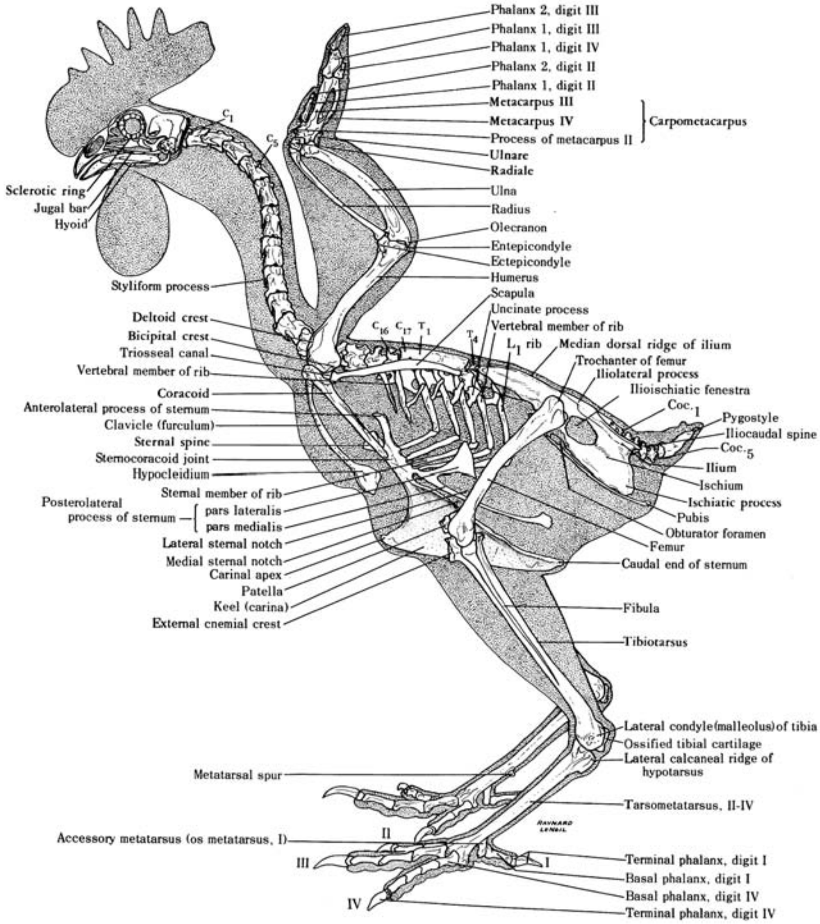

Figure 2.17. *A Lateral View of the Skeleton of a Leghorn Chicken. Abbreviations: C., Cervical Vertebra; Coc., Coccygeal Vertebra; L., Lumber Vertebra; T., Thoracic Vertebra. From Lucas and Stettenhiem (1972).*

POSTMORTEM CHANGES

Understanding the structure and mechanism of muscle contraction in the living animal is essential in comprehending the changes taking place during the conversion of muscle to meat. The living muscle is a complex system that is used to provide movement. In the living animal, all the organs are working in harmony, where it is essential that the internal environment is kept balanced within a very narrow range of temperature, pH, oxygen, CO_2 concentration, etc. Maintaining balanced conditions is called homeostasis, and it is essential for the body's operation in different environments such as high/low temperatures and relative humidity. The body employs thousands of nerve sensors sensitive to physical pressure, temperature, gas concentration, blood pressure, etc., to collect data about external and internal conditions. The information is processed and, if required, corrective actions, such as fluffing the feathers and running to find shelter, are prescribed.

During the conversion of muscle to meat, many of the homeostatic mechanisms are disrupted (e.g., oxygen supply). Stress conditions prior to slaughter also affect homeostatic conditions (see Chapter 3) and, later, meat quality. Stress can arise from activities such as transportation, unloading and immobilization. Immobilization of poultry, which refers to rendering the bird unconscious, is usually the first step in the process. In most countries, there are regulations requiring the use of human immobilization methods to minimize animal pain and distress. For poultry, electrical stunning and gas (CO_2, argon) immobilization are commonly employed (see Chapter 5). In addition to using a proper immobilization method, attention should be given to reducing stress, such as wing flapping before and during stunning (i.e., to minimize hemorrhages in the muscle and incidences of broken bones). The next step after stunning is known as exsanguination or the removal of blood. This step represents the beginning of the major changes seen during the postmortem phase. The removal of as much blood as possible is required, because an excessive amount of blood left in the muscle will result in an overall dark appearance or dark spots. Usually, only around 35–50% of the total blood volume is removed (Chapter 5), and the remaining is mainly held within the vital organs. This occurs because when the blood pressure starts to drop, peripheral blood vessels constrict in an attempt to maintain blood pressure. The removal of blood stops the line of support between the muscle and internal organs such as the lungs, liver and kidney that provide oxygen, detoxify and regulate water, respectively. The first and most serious effect of ceasing the blood flow is the interruption in oxygen supply. In the healthy animal, the oxygen is transferred from the lungs via the red blood cells to the tissue. Once the oxygen supply is cut off, the normal aerobic tricarbocylic acid (TCA) cycle stops. At this point, energy metabolism is switched into an anaerobic pathway that provides the muscle with energy for some extra time. It should be remembered that such an anaerobic pathway occurs in a living, heavily exercised muscle and can be carried out for a certain period of time. In the living cell, lactic acid is produced (i.e., via an anaerobic metabolism pathway) and is then transported to the liver to be resynthesized into glucose or to the heart where it is broken down into water and CO_2 via a specialized enzyme system (Hedrick et al., 1994). When the blood stops circulating, lactic acid will accumulate in the muscle until most of the glycogen stored in the muscle (about 1% of the rested muscle weight) is depleted or until the pH becomes too low for glycolytic enzymes to operate.

The rate of pH decline (Figure 2.18) and the final point to which it reaches, known as the ultimate pH, are very important in terms of meat quality and color development. A normal pH reduction pattern is shown by the middle line in Figure 2.18. This represents a gradual decrease from the neutral pH of the living breast muscle to about 5.8. In some animals where glycogen storage has been depleted prior to slaughter, due to extended activity or struggling, the pH drop will be minimal, and the ultimate pH will stay high. This results from initial low levels of glycogen and, later, limited amounts of lactic acid production; the meat is known as dark firm and dry (DFD). The dry appearance results from a high ultimate pH that is further away from the isoelectric points of the muscle proteins and, therefore, exhibits higher water-holding capacity (see Chapter 14). On the other extreme, the meat's pH can drop very quickly at the beginning of the postmortem process, and this will result in the so-called pale soft and exudative (PSE) meat (Barbut, 1998). In this case, a rapid drop in the pH within the first hour, while the meat temperature is still high, can cause some protein denaturation and, hence, exudative meat. The partially denaturated proteins cannot hold water very well, and the surface appears wet (Hedrick et al., 1994). The color of the meat is pale, and this is the result of more light reflected from the loose muscle structure as compared to the tight structure of the DFD meat.

The process of rigor mortis, which means in Latin "stiffness of death," follows the depletion of energy from the muscle and results in a temporary toughening of the muscle. This state does not take place immediately after slaughter but rather at a certain time after slaughter (Figure 2.19). The reason for this occurrence is the gradual depletion of glycogen and other energy sources (e.g., creatin phosphate) within the cell. When all the energy has been depleted, the actomyosin cross-bridges formed within the muscle structure (between the

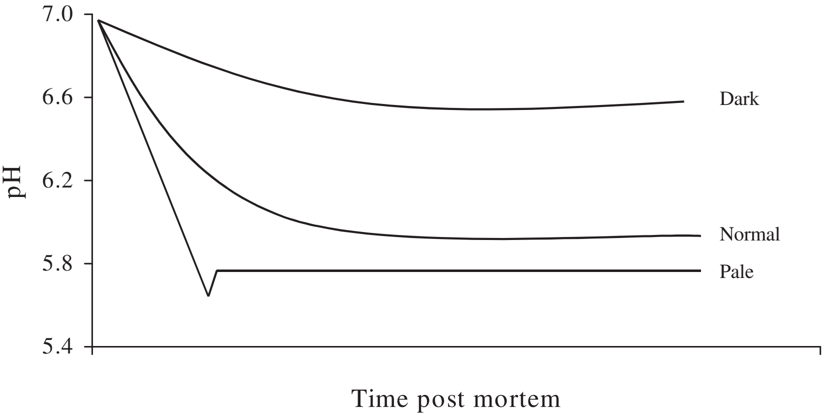

Figure 2.18. *Rate and Extent of Postmortem pH Decline of Chicken Breast Muscle.*

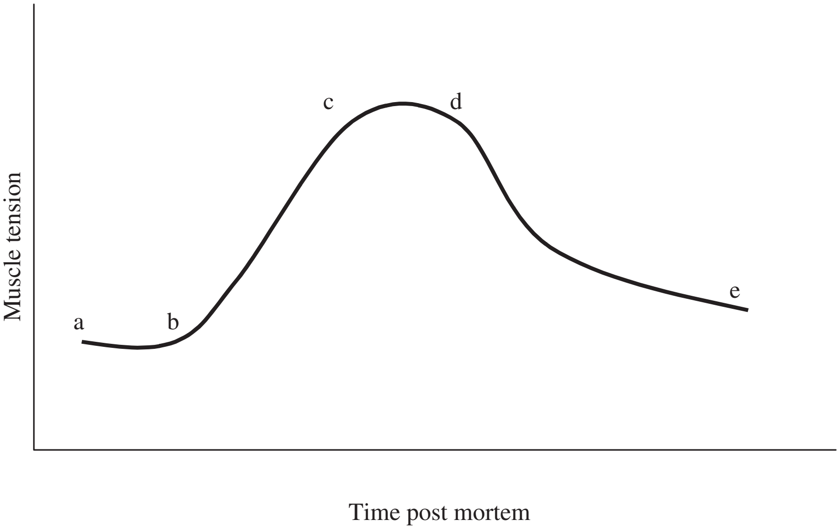

Figure 2.19. *Development of Rigor Mortis Expressed as Muscle Tension Over Time. The Regions Represent: Delay Time a-b; Development of Rigor Mortis b-c; Full Rigor Development c-d; and Rigor Resolution d-e. Time for Each Section Depends on Factors Such as Specie, Degree of Exercise Prior to Slaughter, Stunning Method and Temperature. Adapted from Hedrick et al. (1994).*

thick and thin filaments; Figure 2.12) cannot be broken. The time between slaughter and the onset of rigor mortis is called the delay phase. When all the energy sources have been depleted, the muscle becomes inextensible. After a certain period of time, the muscle starts to become flexible again (Figure 2.19), but this is the result of proteolytic enzymes slowly breaking down the sarcomere components. Some of the major structural changes during the so-called aging process include the degradation of the Z-line (leading to fragmentation and weakening of the myofibrils) and degradation of the proteins titin, nebulin and desmin. The proteolytic enzymes responsible for the degradation consist of two major systems: the calpains and cathepsins. The enzymes vary in their calcium requirements for activation; calcium is available after it was released from the sarcoplasmic reticulum and mitochondria during postmortem aging. Because the enzymes are activated by calcium, some have suggested calcium infusion (i.e., into the meat) to improve tenderness. This actually works and is used more in the red meat industry, where tough meat is a bigger problem. Experiments have also shown that chelating the calcium ion inhibits/slows these enzymes and prevents further improvement in tenderness. It should be noted that at the early stages of the postmortem period, collagen degradation is minimal and does not contribute to improved tenderness.

Temperature during the postmortem process is a critical factor in obtaining high quality meat. An optimal temperature for the postmortem process is between 15–20°C. Therefore, it is recommended to start reducing the muscle temperature as soon as possible after slaughtering. However, very fast temperature reduction can also cause meat tenderness problems. Fast temperature reduction to sub-zero temperatures, prior to the completion of rigor mortis, can result in a condition known as thaw rigor. This is caused by a severe muscle contraction that takes place during thawing, and it is triggered by an excessive calcium release from the sarcoplasmic reticulum into the sarcoplasm. Such a severe contraction results in a release of water and toughening of the muscle. An unrestrained muscle (i.e., dissected and not attached by ligaments to bones) can shorten to over 50% of its original length after thawing (Hedrick et al., 1994). The condition results from a sudden release of calcium ions triggering an intense muscle contraction prior to the depletion of all the ATP. A microscopical examination of such muscles reveals a severe contraction of the sarcomers and the almost complete disappearance of the I-band.

A less severe shortening can occur when the temperature is reduced to below 15°C, but above freezing, prior to the onset of rigor mortis. This situation is known as cold shortening and is also the result of an extensive muscle contraction (Bilgili et al., 1989). The condition is more common than thaw shortening, and damage to the muscle is not as severe; however, it can still cause toughening and moisture loss problems.

Increasing the muscle temperature to above 50°C (higher than normal body temperature) during the rigor process can also result in excessive shortening known as heat rigor. This results from a rapid depletion of ATP and creatin phosphate. However, this problem is not commonly seen by the industry.

Overall, the information presented above indicates that an optimum temperature should be maintained during the rigor mortis process so as to prevent shortening and/or toughening of the muscle during the process. It is commonly suggested that the temperature be kept at 18 +/− 2°C so it is above 15°C but still lower than body temperature (≈39°C for chickens) to suppress microbial growth. Because the rigor process in poultry is much faster than in beef (1–3 hours vs. 12–24 hours, respectively), poultry carcass chilling in modern processing plants starts at about 30–60 min after slaughter and reaches 15°C when rigor is completed or almost completed.

Electrical stimulation can be used after slaughter to speed up the rigor process and overcome some of the problems that might be encountered during rapid chilling. Originally, the process was developed for red meat animals to allow an accelerated processing (i.e., deboning the meat at an earlier stage compared to nonelectrically stimulated carcasses). The process of electrical stimulation includes passing an electrical current through the carcass, which triggers muscle contraction by stimulating the nervous system (Hedrick et al., 1994). Such contraction results in depleting the energy within the muscle and in a rapid onset of the rigor mortis process. Because the electrical pulse used to stimulate the muscle is much larger than the one employed in the live animal, excessive muscle contraction can occur. This, in turn, may result in physical damage to the sarcomere structure (ripping of some of the sarcomeres), which actually also adds to the tenderization effect of electrical stimulation. Besides accelerating the rigor mortis process and allowing deboning at an earlier stage, electrical stimulation can also be helpful in preventing or minimizing cold shortening problems (Sams, 1999). It should be mentioned that the use of electrical stimulation is not as common with poultry as with large beef animals, which have tougher meat to begin with and in which rigor mortis takes about 12–24 hours to complete (vs. 1–3 hours in chickens and turkeys). However, there are currently some poultry processing operations in the United States and elsewhere that are employing the process. Additional discussion on the procedure and equipment used can be found in Chapter 4.

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CHAPTER 3

Catching and Hauling Live Birds

INTRODUCTION

AT the end of the growing phase, essentially all birds are caught, loaded into cages or coops and transferred to a processing plant that may be located either close to or far from the farm. Transferring the live birds from the farm to the processing plant is a relatively short operation; however, significant problems may occur at this stage that potentially increase the rate of downgrading. Catching, loading and transportation exposes the birds to a number of new/unfamiliar conditions and environments. This, in turn, may increase stress/anxiety and negatively affect meat quality. This chapter will describe the common methods of catching and transporting birds to the plant, with an emphasis on steps to monitor and reduce stress. A discussion of manual vs. mechanical catching and loading is also provided, as well as ways to monitor and improve the thermal environment in the transport vehicles.

CATCHING

Manual Catching

Currently, the majority of birds are caught and loaded into cages by hand. In order to achieve the desired catching rate of chickens from a litter floor, it is necessary for the birds to be picked up by the legs. While picking up the birds by the sides is an "ideal" way, in respect to animal welfare, it is not commercially feasible due to the high catching rate required (Kettlewell et al., 2000). Some of the recent welfare guidelines include a description of how birds should be caught and loaded. The recent Royal Society for the Prevention of Cruelty to Animals (RSPCA, 1999) states that "chickens should be caught individually by grasping both legs, just above the feet. If carried in groups, care must be taken to ensure birds can be held comfortably without distress or injury, and carrying distance must be kept to a minimum. No more than three birds should be carried in one hand." In large barns, a loading crew of seven to 10 people catch and crate the birds at a rate of 7,000 to 10,000 per hour. In theory, it is possible to catch and crate the birds by hand with virtually no damage to the birds. However, this is not always the case, because this physically demanding job makes it difficult on the workers to maintain the attitude and concentration required to handle birds carefully over an 8-hour shift (Kettlewell and Mitchell, 1994). Therefore, where problems occur, management should pay attention to training and motivating people to ensure proper bird handling. There are different approaches to employing a catching crew, ranging from employing a permanent crew to hiring people off the street for a single assignment; the former gets much more training and incentives to do the job right. Overall, a significant amount of damage can be inflicted on the birds if the job is not done right, and the workers' motivation is to just get the job over with in the shortest possible time.

During an average shift, a catcher may lift 6 to 16 metric tons of broilers, assuming that a catcher is expected to lift at least 1,000 broilers per hour (2 kg birds over an 8-hour shift). Obviously, this is a difficult backbreaking job. Management usually has to deal with absenteeism, low moral and turnover of the workers. In terms of animal welfare, bruising of legs, wings and breasts may occur on as many as 25% of the broilers processed in the United States and as many as 20% of some flocks in the United Kingdom (Lacy and Czarick, 1998). In order to keep injuries to a minimum, clear guidelines should be established and enforced by farmers, catching supervisors and processors. It is difficult to assess injury, except gross insults, to birds prior to loading, as the operation precludes easy inspection of the birds at the farm after they have been loaded. It is sometimes possible to ascribe retrospectively any injury or downgrading that might have occurred at the farm, but this is detected at unloading rather than on the farm (Kettlewell et al., 2000).

Transport Containers

Overall, there are three basic types of containers: loose crates, fixed crates and the new style of modular containers.

Loose crates are the oldest type of transport container initially made of wood and string/wire. These are still used today in different parts of the world, but are constantly replaced by plastic crates of varying sizes (typical size for a chicken crate is 80 × 60 × 30 cm). The small size container, which can hold about 14 birds, makes it easy to handle. Normal loading procedures require that birds be carried from the barn to the truck, rather than by taking the containers into the barn for loading; however, in some cases, the crates are carried to the truck or placed on a palette and later moved by special loading equipment. The birds are loaded into the crates through a relatively small opening, which limits their ability to "escape." This limited aperture size, however, also means that when loading groups of birds, there is a chance for physical injury, especially to the wings (Kettlewell et al., 2000). Overall, the system offers a flexible, low equipment cost approach to loading and transporting the birds to the processing plant.

At the plant, the crates are usually unloaded onto a conveyor system that moves the crates to the shackling line where birds are removed from the crates. Also at this stage, care should be exercised as to not hurt the birds, damage wings, etc.

Fixed crates are built onto a truck and represent an integral part of the trailer (Figure 3.1). The crates are usually arranged in two banks with loading openings facing outside the trailer. The number of crates depends on the size of the birds (e.g., chickens, turkeys), truck size, etc. Typically, there are eight layers of 12 crates, as seen in Figure 3.1, making 96 crates. The loading is done from each side of the trailer and requires that the birds be carried from the house and either loaded directly or passed to another person positioned on the truck to allow the filling of the upper level crates. In the case of turkeys, a conveyor system, shown in Figure 3.1, can be used to place the birds in the different crates by moving and elevating the end of the belt. This system can be used with turkeys that will walk on the conveyor belt as opposed to chickens that will tend to sit on the belt. According to the manufacturer, the system can handle 2,000–3,000 turkeys per hour. In the case of chickens, the process is fairly labor intensive and may require passing the birds to another person. This transfer is another opportunity for injury to the birds before they are loaded. Kettlewell et al. (2000) have observed that when

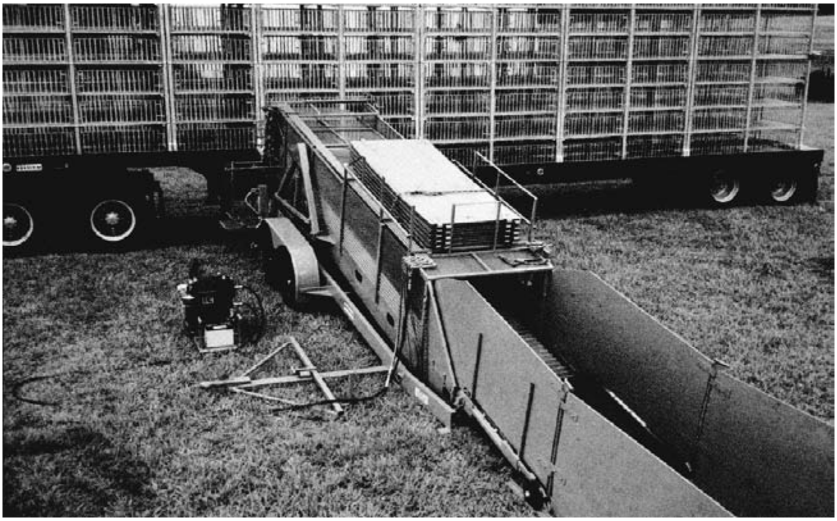

Figure 3.1. *A Fixed-Crate System that Is an Integral Part of the Truck's Trailer. A Conveyor System for Loading Turkeys to the Different Height Crates Is Shown. Courtesy of Bright Coop, Nacogdoches, TX.*

the system is used to carry pullets, there is a very low level of injury which contrasts with the higher level seen when moving spent hens. This disparity may be, in part, due to the better tolerance of pullets to handling and transporting as compared to laying hens, which are more prone to broken bones due to calcium depletion and osteoporosis. When the truck arrives at the processing plant, it is usually driven to an unloading area (close to the shackle line) where hydraulic platforms can be used to assist the unloading crew in reaching the birds at the different levels. This is manual work that requires catching the birds and hanging them on the shackle line.

Modules represent a fairly new development in transporting poultry. This system relies on larger containers (Figure 3.2) requiring mechanical handling moving off and on the truck. This system represents a fundamental change

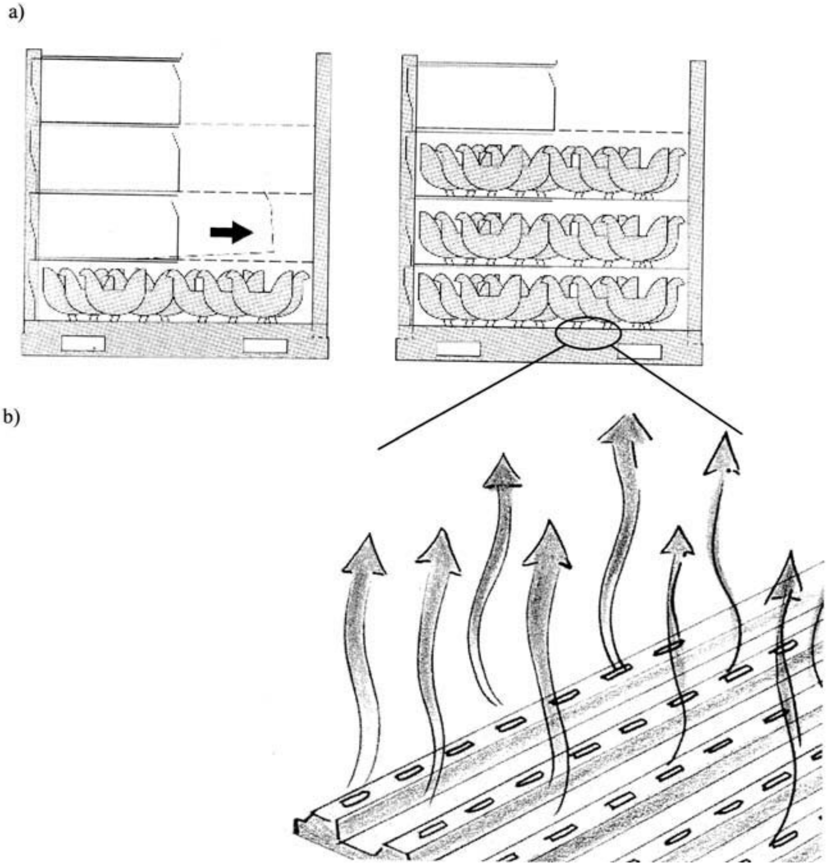

Figure 3.2. *A Modular Crate System Used to Transport Birds from the Farm. Note the Large Opening for Loading. When a Tier Has Been Loaded, the Overhead Half-Floor Is Pulled Forward. Also Showing Air-Flo Floor Design Allowing Adequate Airflow with Minimal Fecal Contamination. Courtesy of Stork Corp., Boxmeer, The Netherlands.*

from the two previous systems, where mechanization and improved welfare are taken into consideration. Overall, there are two basic modules that include the loose drawer and tipping modules. The loose drawer module comprises a number of plastic drawers positioned within a metal framework. The number of drawers depend on the size of the birds, where a typical size for broilers would be 1.2 m wide, 2.4 m long (equivalent to the full width of the transport vehicle) and 0.22 m high. This is designed for a capacity of about 25 birds, each weighing 2 kg. The stocking density can obviously be adjusted to suit the size and live weight of the birds. The crates are moved by a forklift into the barn and positioned at strategic locations for catching. A typical manual collection rate of 1,000–1,500 birds per man hour is expected. The large opening at the top reduces injury to the birds during loading and unloading. At the processing plant, the modules are unloaded onto a conveyor belt that transfers them close to the shackling line. The easy and fast catching, through the large openings, reduces stress and injury to the birds as they are moved onto the shackle line.

The tipping-type modules were named for the unloading method used to move birds onto the conveyor belt at the processing plant. This modular cage arrangement is also positioned inside the barn, and the hinged front doors are opened to allow the loading of each crate. Sometimes the container is lightly tipped backwards to allow birds to slide to the back of the compartment. The loaded modules are taken by a forklift and put on the truck. At the processing plant, the modules are positioned on an automated handling system, where they are moved to a conveyor belt used to transfer them close to the shackling line. Some of the new unloading designs include a series of conveyors that align with each crate level so that the birds can easily come out of the crate. Other designs do not have this feature, and the birds are tipped onto a cross conveyor belt (Kettlewell et al., 2000).

Mechanical Harvesting

The catching operation still remains one of the few aspects of broiler production that is not very automated. Overall, most birds, around the world, are loaded manually; however, this is starting to change as poultry companies are beginning to automate this step. A few systems have been developed and tried over the years, some having totally failed, and others slowly progressing into commercial systems. A description of the different concepts is provided below.

One of the earliest designs was the large foam rubber paddle loader that was a self-propelled harvester developed in the 1980s in Northern Ireland. The system captured the birds with large foam rubber paddles that rotated down on top of the birds and then pushed them onto a conveyor belt. The belt carried the birds to a loading platform where they were deposited into modules made of a series of layered compartments that were carried on the back of the machine. The loading platform was equipped with a weighing device that indicated to the operator when a crate was full. The whole assembly was mounted on a truck-powered vehicle, which maneuvered inside the barn through almost any type of litter. Several companies started to use it commercially, but in the end, the equipment proved to be too slow, unreliable and costly to maintain (Kettlewell and Turner, 1985).

A vacuum system was an attempt to use a pneumatic system that could best be described as a large vacuum cleaner. The birds were suspended in air as they passed through a tubing system while their feathers helped to prevent or reduce bruising. The birds were placed by hand in a funnel-like aperture and pulled by suction through tubing to crates on a truck. The operator directed the stream of birds exiting the tubing into the crates. Problems with the system were encountered when birds were placed in the funnel too quickly, resulting in malfunction and unacceptable injuries to the birds (Kettlewell and Turner, 1985).

A built-in conveyor belt was developed and tried in Georgia in the early 1970s. It consisted of a mechanized growing, harvesting and transporting system. The barn was equipped with a permanent, recessed conveyor belt built into the concrete floor. During catching, the birds were mechanically herded onto the recessed belt using large paddles that rolled on metal tracks. The herding device was equipped with lights and a horn that were activated to encourage birds to move. The conveyor carried the birds out of the barn to a short, inclined conveyor that lifted them to the rear of a transport truck. Overall, the harvesting aspect was complex and never reached commercial practice.

A collecting mat system was developed in The Netherlands. Mats were laid in sections of the barn's floor a few hours prior to catching. Later, the mats and the birds on top of them were mechanically pulled from the barn one at a time, and the birds dropped into stackable crates as the mats were rolled up by a machine. Overall, the process involved a lot of manual labor when placing the mats. In addition, the process was most likely not practical in North America due to differences in barn design.

Tined fork was developed in the early 1980s and involved catching the birds by scooping them off the floor with a large tined fork. The fork was attached to a small, front-end loader and could lift 100 broilers at a time. Although the pickup mechanism was reported to be effective, the other procedures for transferring the broilers to crates were judged to be less than satisfactory for this purpose.

Rubber-fingered cylinders is a pickup mechanism consisting of a rotating drum with soft rubber fingers that lead the birds onto a conveyor belt (Figure 3.3). It is crucial that the long rubber fingers be soft enough not to hurt the birds but also firm enough to not let them escape or flap their wings. The spacing between the fingers, rotation speed and the speed at which the machine approaches the birds are critical. This system was developed in the

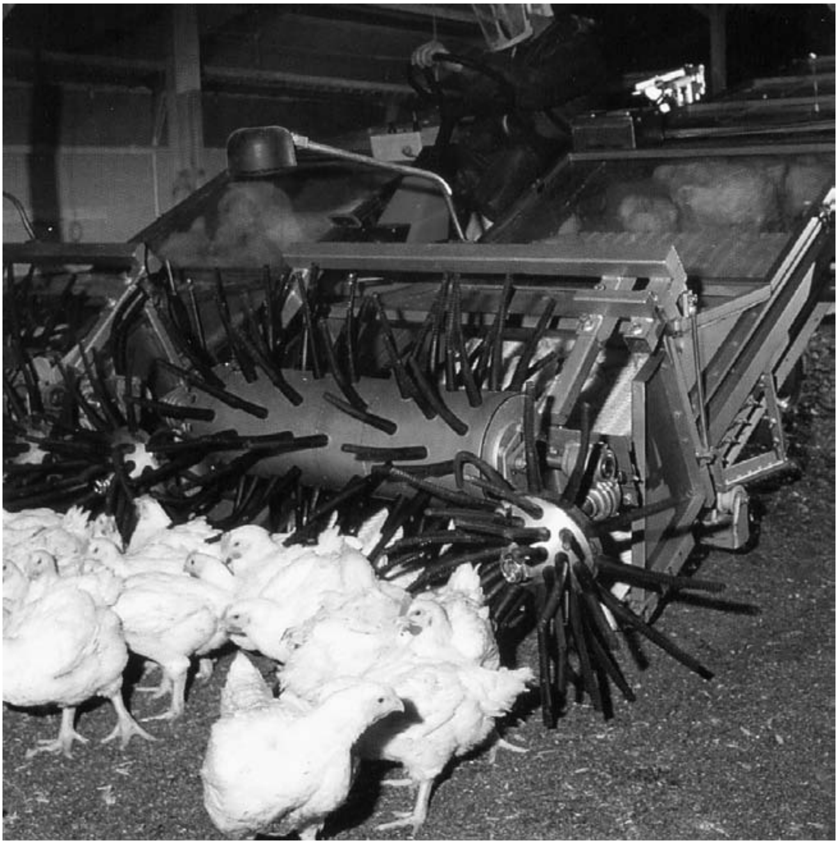

Figure 3.3. *Rotating Drum Design Used for Mechanical Harvesting of Broilers. Courtesy of Anglia Autoflow, Norfolk, United Kingdom.*

United Kingdom and later modified to allow compatibility with the type of cages typically used in North America. The system draws and lifts the birds onto an inclined conveyor (Figure 3.4) that carries the birds to a caging system designed to fill standard dump-type cages at the rear of the machine. The harvester is a front-wheel drive machine propelled by a 70 HP diesel engine. The rear wheel is used for steering and allows for good maneuverability. The drive system is hydraulic, and the machine is reported to be extremely adept at picking birds off the ground (in a promotional demonstration, the manufacturer showed the machine picking up inflated balloons without popping them). The harvester is designed to catch about 5,000 birds per hour, which is close to the average rate of a manual catching crew. A three rotating drum system (three short vertical drums covered with rubber fingers) is a different design marketed by a Danish company, and is designed to handle 7,000–8,000

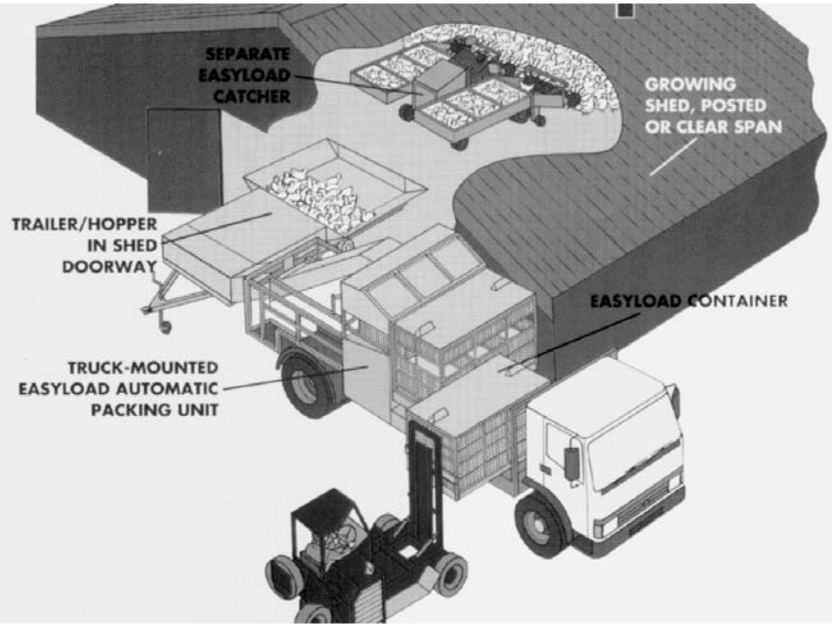
SEPARATE EASYLOAD CATCHER
GROWING SHED, POSTED OR CLEAR SPAN
TRAILER/HOPPER IN SHED DOORWAY
EASYLOAD CONTAINER
TRUCK-MOUNTED EASYLOAD AUTOMATIC PACKING UNIT

Figure 3.4. *A Complete Mechanical Harvesting System. Courtesy of Anglia Autoflow, Ltd., Norfolk, United Kingdom.*

broilers per hour with a crew of four people. Usually, the operation is done at night or when the barn lights are very dim. The system is powered by a 43 HP engine, has a telescopic conveyor belt with a maximum scanning range of 24 m and has steering and operation that can be maintained by a remote control. The birds are loaded into one of the modules described earlier in the chapter.

An improved vacuum-based system was manufactured by a Dutch company. The machine is a self-propelled, vacuum-based system that has a pickup head of about 2.5 m wide that can swing back and forth, extending the width of the catching area to 5–6 m. Broilers that come in contact with the pickup mechanism are exposed to gentle suction that lifts them onto a conveyor belt and transfers them to a cage-filling device. The cages are then automatically stacked and placed onto a pallet and moved by a forklift as described above.

Benefits of using mechanical harvesters include the following:

- improved working conditions for the catching crew
- lower stress and fewer bruises to the birds
- reduced labor costs

The topics of employee health and safety, as well as animal welfare, have received greater attention during the past decade. Therefore, any advancement in mechanical harvesters is closely followed by the poultry industry. It was reported that at the beginning of the year 2000, there were only two mechanical harvesters (similar to the one shown in Figure 3.4) operating in the United Kingdom, each capable of harvesting 35,000 birds per day (Kettlewell et al., 2000) and few operating in the United States and Australia. But, it seems that their use will grow as more companies are showing interest in the technology.

Comparing the bruising rate of manual vs. mechanical harvesting indicates some of the benefits of using a mechanical harvester (Table 3.1). As previously indicated, a manual catching crew can theoretically load the birds with no injuries. However, in a real-life situation, stress to the birds and to the people trying to catch them, as well as time constraints, usually result in a less than optimum situation. Table 3.1 shows that leg bruising was reduced by more than 50% when mechanical harvesting, employing the rubber-fingered rotor machine, was used. Reduction was also seen in back and breast bruising; however, a slight, nonsignificant increase in wing bruising was observed. Previous reports concerning the tined scoop machine indicated less bruising compared to manual catching and, for the vacuum system, 4–8% less bruising was reported (Lacy and Czarick, 1998).

In one of the few scientific publications comparing mechanical and manual collection, Duncan et al. (1986) suggested that stress could be reduced and welfare improved by a properly designed mechanized harvester. They have investigated a prototype of a rotating rubber-finger harvester developed at the Silsoe Research Institute, U.K. Compared to manual collection, they showed that indicators such as time required to return to normal heart rate and duration of tonic immobility were significantly lower in birds caught by the mechanical harvester. The study, however, did not examine the subsequent placing of birds into transport crates because such equipment was not available at

Table 3.1. Mean Percentage and Standard Deviation of Carcass Bruising Observed on Hand Harvested and Mechanically Harvested (Rubber-Finger Type) Broilers Following Processing.[a] From Lacy and Czarick (1998). With Permission.

	Bruising			
	Back	Breast	Leg/Hock	Wing
Harvesting Method	(%)			
Hand harvested	3.5 (2.5)	1.0 (2.0)	16.5[b] (5.9)	10.5 (3.4)
Mechanically harvested	2.0 (2.0)	1.5 (1.0)	7.0[c] (3.3)	11.5 (3.0)

[a] Four samples of 50 birds each were graded by processing plant personnel for the two catching methods.

[b,c] Means within a column with different superscripts differ significantly ($P \leq 0.05$).

the time. Duncan (1989) suggested that manual handling, whether gentle or rough, is a cause of stress by its nature. Others have also indicated that direct contact with humans, especially if infrequent, is a physiological stressor to chickens. Herding or conveying was reported to cause less stress than hand catching (Duncan, 1989). The basic method used by a mechanical harvester (shown in Figure 3.4, similar to the concept used in the study) resembles herding and conveying. Such a method would actually reduce direct contact between humans and broilers, and it seems very likely to improve the bird's welfare from stress and injury standpoints.

Lacy and Czarick (1998) provided some cost estimates regarding the purchase and use of a mechanical harvester. For example, labor costs for a typical nine-person catching crew would total approximately $215,000/year. The labor costs for a three- to four-person crew required to operate the mechanical harvester are estimated at $72,000/year, resulting in a cost of labor reduction of over $143,000/year. Assuming a cost of $175,000 for a mechanical harvester, the reduction in labor cost alone would pay for a harvester in less than 15 months. According to Lacy and Czarick (1998), this payback estimate does not include additional savings likely in reduced bruising to birds, reduced workmen's compensation claims and/or reduced worker healthcare costs.

HAULING

Minimizing stress during transport is an important issue from both an animal welfare and meat quality aspect. Over the past decade, both issues have received growing attention, particularly because most poultry, around the world, are transported to processing plants. In Europe alone, the number is around 3.5 billion broiler chickens per year, with the majority of the production in France (21%), England (17%), Spain (17%), Italy (13%), the Netherlands (10%) and Germany (7%) (Mitchell and Kettlewell, 1998). The birds are raised on large farms scattered around the country at geographically dispersed sites that necessitates their being transported, often over long distances, to centralized processing plants. The birds may be exposed to different stressors during transit including thermal variations, vibration, motion, acceleration, withdrawal of feed and water, noise and social disruption. The combined effect of these factors may range from mild discomfort and aversion to death. In England, it has been reported that up to 40% of the "dead on arrivals" (DOA) are attributable to transport stress (Bayliss and Hinton, 1990), and that mortality increases with journey length. The authors have also indicated that the average broiler journey in England is three hours or less, but that occasionally, birds might be confined to the vehicle for up to 12 hours. The same is true in North America, where the so-called long journeys can extend to 5 hours, and time on the truck can extend to 12 hours. It should be remembered that catching the birds already results in profound physiological stress. Behavioral and physiological responses can be used to characterize the stress(es) imposed on the birds during transportation. Based on measurement of heart rate, plasma corticosterone concentrations and tonic immobility, Duncan (1989) and others have suggested that transportation imposes stress. Increased plasma corticosterone following a road journey indicates apparent activation of the hypothalamo-adenohypophyseal-adrenocortical axis, which is consistent with other observations of an increase in heterophil:lymphocyte ratio. Transport stress can also induce tissue dysfunction and damage that are reflected by increased plasma activity of intracellular muscle enzymes such as creatin kinase.

The major stress factor, during transportation, seems to result from changes in environmental temperature. In the past, only a few attempts were made to study and model the effects of heat on metabolic rates in birds during transport. Webster et al. (1993) suggested that during a normal transport, well-feathered birds can only experience thermal comfort over a narrow range of ambient temperature. They proposed that stress could be minimized by an appropriate control of airflow within the truck, both in motion and at rest (i.e., minimal natural ventilation during rest/stop time). More recently, Mitchell and Kettlewell (1998) reported on comprehensive temperature modeling that was used to generate guidelines for poultry transportation. Their development work will be used to illustrate ways of monitoring the thermal microenvironment within the truck, measuring stress and providing some practical guidelines.

The authors used a typical modern broiler transporter with a modular container system that can carry approximately 6,000 birds of 2 kg body weight. Stocking density was 53 kg/m^2 using crates $1.3 \times 0.7 \times 0.25$ m in size, loaded with 21–22 birds in the summer and up to 23 birds in the winter. The crates were perforated by vertical slits (10 mm wide) at 55 mm center spacing. The truck had a solid headboard and a roof, but the rear was open. Temperature and relative humidity (RH) probes continuously monitored the conditions at six locations. The probes were located within the transport containers (at the same level of the birds) and, thus, reflected the precise thermal conditions experienced by the broilers. Ambient temperature and airspeed over the vehicle were also measured. The positioning of all probes allowed a three-dimensional thermal mapping of the transport environment in the summer (curtains left open) and winter (curtains closed). An example of the data obtained in the winter is provided in Figure 3.5. The data indicate that during the winter (curtains closed), substantial increases in temperature and vapor density (VD), above ambient values, were recorded; elevations of mean temperature of 14.5°C and VD of 6.2 g/m^3 were noted. During the summer, only a small gradient of 2–5°C was measured (data not presented here). Figure 3.5 shows that a gradient existed from front to rear of the truck, and a "thermal core" was identified toward the upper front of the truck where ventilation was

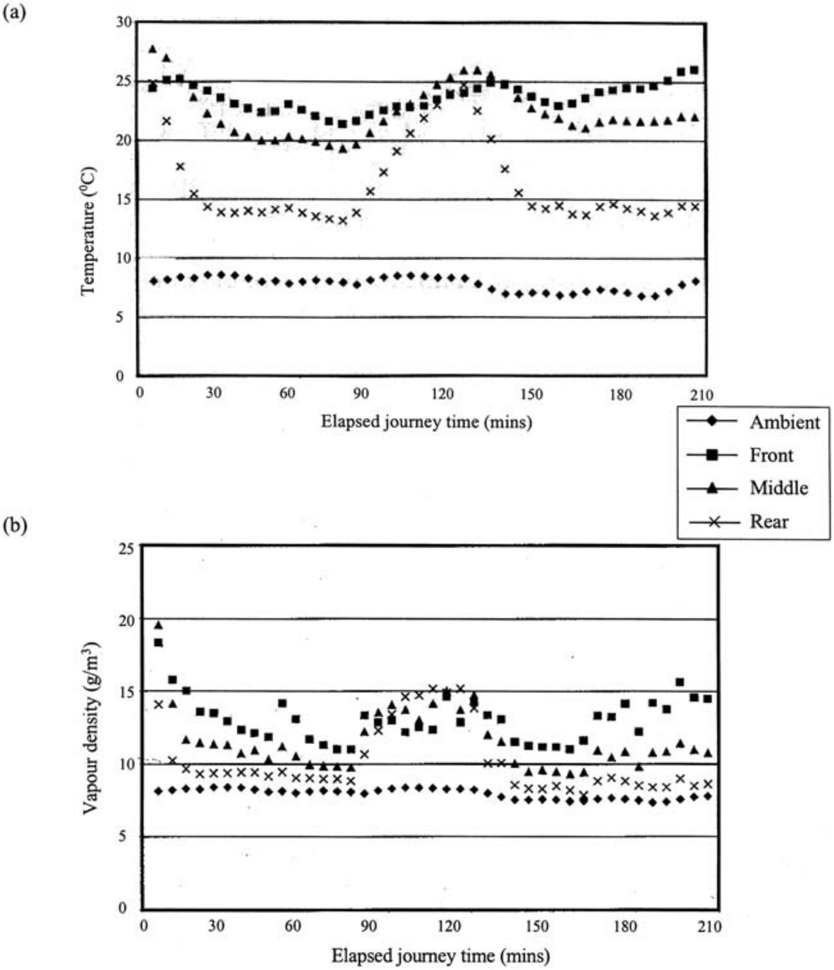

Figure 3.5. *Variation in Temperature (a) and Water Vapor Density (b) in Three Locations in a Poultry Transporter with Elapsed Time during a Typical Winter Journey (Curtains-Closed Configuration). The Vehicle Was Stationary during a Mandatory "Driver Break" between 78 to 118 minutes. From Mitchell and Kettlewell (1998). With Permission.*

minimal, and the risk of heat stress was proportionally greater. The temperature and VD increased when the vehicle stopped for the mandatory driver-break period between 78–118 minutes. This is a very important point, because a lot of trucks do not have forced ventilation and rely only on "natural ventilation" while the truck is moving. During transport, temperature and VD were the highest and fairly constant in the "thermal core." Under reduced ventilation conditions (truck stopping), the temperature observed in the summer, accompanied by higher VD, actually put the birds under higher thermal load. A value called apparent equivalent temperature (AET) was calculated to characterize the birds' responses to quantified thermal conditions. The value takes into account water vapor pressure, the psychometric constant and temperature. The AET value basically shows the "effective temperature" that the birds will experience and indicates that as relative humidity increases (at a given temperature), it will be more difficult for the bird to lose heat via panting and, therefore, perceive a higher body temperature. The value is related to the wet-bulb temperature and describes the total heat exchange between a wetted surface and the environment. When birds are transported in commercial containers, constraints upon behavioral thermal regulation and the practical reduction in surface area (important for sensible heat exchange) can increase the birds' reliance on evaporated heat loss at a relatively low wet-bulb temperature. Overall, the influence of heat loss may be more pronounced on a crate of birds than on an individual bird under similar conditions. Mitchell and Kettlewell (1998) reported mean AET values of approximately 50°C, with a maximum of around 60°C during the summer (curtains open). During the winter (curtain-closed configuration), the equivalent heat load ranged from 60–80°C. They noted that these data were derived from "typical" journeys and, therefore, the practical range of AET, under commercial conditions, may exceed those reported here, particularly during "warm" periods in spring and autumn when trucks may run in the curtain-closed configuration. To show the effect of those AET values on physiological responses associated with stress, the authors conducted laboratory "in-crate" experiments in which ten birds were studied in each treatment (Table 3.2). Body temperature was measured internally, and blood samples were obtained at 0 and 3 hours after simulated transport conditions. The AET values were achieved at "in-crate" temperatures between 22–30°C and VD of 10.5–27.0 g/m^3. Confinement of the birds

Table 3.2. Body Temperature and Plasma Creatin Kinase (CK) in Broiler Chickens Exposed to a Range of Thermal Loads (θ^*_{app}) for 3 Hours Under Simulated Transport Conditions. Values Are Given as the Mean ± SD (n = 10). From Mitchell and Kettlewell (1998). With Permission.

	Body Temperature		Plasma CK Activity	
	T_0	T_1	T_0	T_1
θ^*_{app}	--------------- (C) ---------------		--------------- (C) ---------------	
45.0	41.6 ± 0.13	42.0 ± 0.25	693 ± 257	888 ± 324
58.0	41.7 ± 0.17	42.4 ± 0.29	696 ± 296	1,043 ± 432
70.4	41.5 ± 0.17	42.5 ± 0.30	652 ± 178	996 ± 241
81.1	41.5 ± 0.11	43.0 ± 0.33	830 ± 323	1,205 ± 393
91.5	41.3 ± 0.23	44.6 ± 0.33	810 ± 215	1,239 ± 410

in the crates tended to induce hyperthermia at all heat loads. At an AET of about 70°C, the hyperthermia became marked, and at an AET of 80°C or more, the hyperthermia was profound and could be a life-threatening occurrence. Plasma creatin kinase increased in all groups, perhaps reflecting the physical stress of these conditions. Levels of above 1,000 IU/L or greater resulted from exposure to all AET above 45°C, although the response tended to be proportional to AET. An increase of 45–50% in creatine kinase, associated with exposure of AET of 81.1 and 91.5°C, suggests a significant disruption of sarcolemmal integrity and, therefore, significant muscle damage. A significant increase in the cortical steroid secretion at AET above 70°C was also observed. This was followed by a disturbance in the acid-base balance and partial CO_2 due to thermal panting (data not presented here). Overall, the stress profiles obtained suggest that at heat loads associated with AET of 45–50°C, physiological stress would be minimal or mild. At between 50 and 70°C, moderate to severe, and increasing physiological stress, associated with failure of several homeostatic systems, will be observed with potentially increasing mortality. When AET reaches 90°C and above, extremely severe stress will occur with a possible catastrophic failure of thermal regulation, profound hyperthermia and collapse of vital systems. Therefore, it was suggested that temperature and humidity conditions constituting AET of 65 or greater should always be avoided in commercial practice by means of appropriate preventive strategies. The authors have developed a method for an online routine monitoring of the environment within the thermal core of commercial vehicles. The program utilizes the physiological response model data to provide warning and indicate the risk of impending heat stress during the journey. Temperature and humidity data collected within the transport space are used by a computer program to calculate AET values and warn the driver. Simple modifications such as adjusting the side curtains can be employed, during the journey, to reduce risk of heat stress. Using this system has already been credited in improving vehicles' design and ventilation systems. Thermal data pertaining to the conditions within the truck (Figure 3.5) show the complexity of the microenvironments present in a commercial truck. If the average metabolic rate of a 2 kg bird is 15 W, then an excess of 90 kW of heat (calculated for 6,000 birds) is produced as well as the associated obligatory metabolic water production (10.5 g/h; or 63 kg/h for 6,000 birds) that must be dissipated by ventilation in a typical broiler truck. Any impairment of airflow through the structure will result in the accumulation of heat and moisture and impose heat stress upon the birds. The consequent stimulation of thermal panting will increase evaporative water loss from the birds, adding to the moisture load, further precipitating heat stress and creating a vicious spiraling cycle of hyperthermia. The installation of side curtains will create conditions of low ventilation that can exacerbate this process and lead to the creation of a "thermal core" in which the risk of heat stress is even greater. The core is located immediately behind the headboards and toward the top of the truck's compartment. The thermal conditions in this area may deteriorate further when the truck stops or if the stocking density is high.

New truck designs take these factors into consideration, and an airspace between the left and right modular crate systems can be found on some trucks. The space should be kept clear and used to improve airflow in between the cages. In some other designs, the roof of the truck can be elevated so that when the truck stops, the driver can raise the roof and significantly improve the airflow (i.e., preventing hot air and high humidity conditions at the upper cages). Figure 3.6 shows an improved truck design that also allows roof height adjusting. Roof height adjustment is used to facilitate loading and unloading of the module crates (shown in Figure 3.2). Other improvements include a special floor design (Figure 3.2) that allows better air movement on the truck, without causing problems with droppings from upper cages.

Overall, the potential heat stress increases when the outside temperature and/or humidity are elevated, when the vehicle stops, curtains are drawn, etc. The risk is reduced when stocking density is reduced and when vapor density and temperature rise are minimized by adequate airflow. In the winter when curtains are closed, a "paradoxical heat stress" may occur within the "thermal core" even when the temperature outside is very cold. Dissipation of temperature and humidity gradients and proper distribution of the thermal load within the truck should, therefore, be a primary objective when designing a new truck or improving the ventilation system of an existing truck. An example for calculating air velocity was also provided by Mitchell and Kettlewell (1998), showing that when the outside temperature is 20°C and the RH is 50%, the water vapor density is 8.6 g/m^3. If moisture addition, from birds within the truck, increases the RH to 90% (without any change in temperature), it will raise the vapor density to 15.6 g/m^3. If water addition (via panting) from

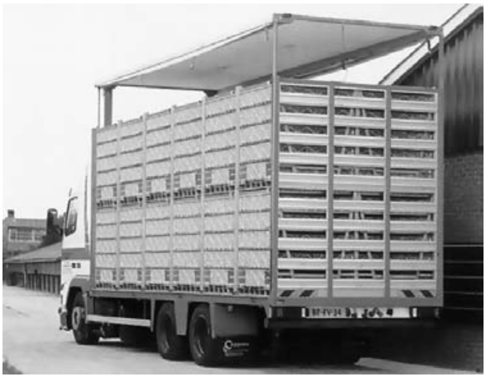

Figure 3.6. *A Truck Design that Allows Roof Height Adjustment. Courtesy of Stork, Inc., Boxmeer, The Netherlands.*

a 6,000 bird truck is 63 kg/h, the humidity status quo would require an airflow of 2.5 m^3/s. This theoretical calculation assumes no temperature rise and a homogenous internal environment that may not actually exist in a commercial truck. However, this calculation demonstrates the approach for calculating ventilation requirements based on temperature, humidity and physiological requirements of the birds.

Figure 3.7 shows the combination of temperature and humidity of the apparent equivalent temperature (AET) yielding a value of 64°C, which is based on the physiology of the bird. Based on the information previously described in the chapter, one can calculate requirements for ideal conditions on the truck. For example, the extreme theoretical values producing an AET of 65°C are 65°C in completely dry air and 22°C at RH of 100%. Air temperature of 40°C and 21% RH will result in the same value (Figure 3.7). Overall, an RH of <50% is not a realistic value within the thermal core of commercial trucks, regardless of temperature. Therefore, the absolute maximum permissible dry-bulb temperature should not exceed 30°C. A more realistic RH range is 70–80%; therefore, the temperature should be kept below 25–26°C with adequate ventilation that can reduce the water vapor load. By monitoring and controlling the thermal microenvironment, it is possible to minimize heat stress and improve the welfare of the birds during transit. It is important to emphasize that the calculations presented here refer to a stocking density of about 53–58 kg/m^2 and a transit time of about 3 hours. These conditions compare favorably with the EU standards (EC 91-628, 1993).

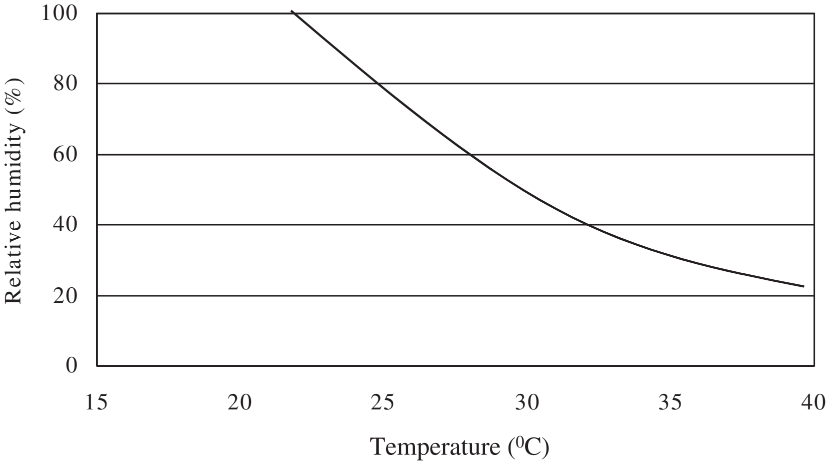

Figure 3.7. *Dry-Bulb Temperature and Relative Humidity Combinations Yielding an Apparent Equivalent Temperature of 64°C, the Recommended Acceptable Upper Limit for the Thermal Load in the Core of a Commercial Poultry Transporter. From Mitchell and Kettlewell (1998). With Permission.*

The results of a test done using the materials discussed above are reported in Table 3.3. In this study, a truck with a conventional ventilation system (vehicle B) was compared to an improved ventilation system (vehicle A). The modifications were based on mathematical and physical modeling of the pressure fields surrounding the conventional truck to identify locations of pressure gradients that can assist in driving natural ventilation when the truck is in motion. The modified truck was also capable of carrying an additional two modules (approximately 500 broilers). A matched control, back-to-back, alternate journey over identical routes on four successive days were conducted. Temperatures and RH were recorded, as well as assessments of the physiological stress experienced by the birds in both trucks. In the standard truck, the average temperature was 28.7°C accompanied by 63% RH (vapor density of 17 g/m^3), resulting in AET of 68.8°C. The latter value was above the recommended level previously discussed and resulted in physiological stress to the birds, particularly as measured by a marked elevation in the heterophil:lymphocyte ratio. In the modified truck that had an improved ventilation system, the same external climate conditions resulted in an average core temperature of 22.5°C accompanied by a 51% RH (vapor density of 10.2 g/m^3), and these conditions provided an AET value of 45.1°C. As a result, physiological stress indicators such as those measured by creatine kinase and heterophil:lymphocyte ratio were lower. The experiment clearly demonstrates the benefits of using physiological and physical parameters to study and improve truck design and provide the birds with improved welfare conditions. The modifications also resulted in lower mortality and in the ability to increase truck capacity or the number of birds delivered by about 10%.

Table 3.3. Comparison of Environmental Conditions (Thermal Core), Physiological Stress Responses and Productivity on Two Broiler Transporters on Four Matched Journeys on Consecutive Days.[a]
From Mitchell and Kettlewell (1998). With Permission.

Variable	Vehicle A	Vehicle B
Core temperature, C	22.5	28.7
Core vapor density, g/m^3	10.2	17.8
Creatin kinase, IU/L	310	407
Heterophil:lymphocyte	0.30	0.97
Mean load (no. of birds)[b]	6,120	5,580
Mean dead-on-arrival, %	0.43	0.49
Total birds delivered	24,375	22,210

[a] Each journey lasted 3 hours, the mean external environmental temperature was 11.7°C, with a water vapor density of 6.6 g/m^3. Vehicle A had a modified ventilation system aimed at improving thermal homogeneity within the load, whereas Vehicle B was unmodified. The modified vehicle had an increased capacity of two extra modules.

[b] Birds were loaded at 21 to 22 per crate.

Another important factor in minimizing downgrading is the type and condition of the truck used to transport the birds. Barbut et al. (1990) reported that employing new fixed-crate-type trucks with wire doors resulted in significantly less downgrading compared to using older model fixed-crate-type trucks with board doors. Using the old-style board-door cages resulted in higher incidences of half-wing trim, bruised drums and breast scratches (Table 3.4). The newer wire-door-type cages (130 cages on the truck; 1.12 × 1.20 × 0.43 m per cage) were well maintained, and the doors completely blocked the opening right to the floor of the cage. In the older board-door-type cages (140 cages on the truck; 0.95 × 1.02 × 0.33 m per cage), maintenance was not as good, and trapped wings could be seen. This obviously resulted in more downgrading problems, which were corrected after the release of the study's results. In order to separate the damages resulting from bruising on the farm vs. bruising on the truck, the authors examined selected samples under the microscope. This histological study of bruised tissue was undertaken because the samples were obtained after the birds had been scalded (i.e., skin exposed to high temperature), and it was difficult to use distribution analysis of red blood cells as the only criteria of the age of a bruise. Tissues were sectioned (5 μm) and stained with hematoxylin and eosin and examined at low and high magnifications. The presence and number of macrophages, pigment, cells and debris within macrophages were used to determine the age of the bruises and scratches. Unloading and line-damaged tissue contained no macrophages. Loading and transportation-damaged tissue contained no or very few macrophages. Farm-damaged tissue contained small to moderate numbers of

Table 3.4. Effects of Truck Type on the Percentage of Turkey Downgrading.[a] From Barbut et al. (1990). With Permission.

Cause of Downgrading	Type of Truck: Wire Cage Min. (%)	Wire Cage Max. (%)	Wire Cage $\overline{X}$ (%)	Board Min. (%)	Board Max. (%)	Board $\overline{X}$ (%)	Significance of Difference
Wing trim	1	16	7.27	0	22	7.40	NS
Half-wing trim	4	18	10.03	3	23	12.26	$P < .05$
Bruised drumstick	0	19	1.83	0	7	2.44	$P < .05$
Breast scratches	0	2	.10	0	3	.22	$P < .05$
Drum thigh trims	0	1	.07	0	1	.04	NS
Back scratches	0	10	1.33	0	11	1.48	NS

[a] Values are the means ($\overline{X}$) of 28 trucks; 100 turkeys per truck.

macrophages; many had engulfed pigment, cells and debris inside the macrophages. The method was useful in developing a set of photographs that were later used, by a trained technician, to record data on the processing line. Generally, bruises that were bright or dark red and with a good line of demarcation were found to be under 19 hours old, indicating fresh hemorrhages.

Overall, further study of factors such as the type of truck, stocking density, frequency and duration of rest periods should be of great interest to the poultry industry. A multidisciplinary approach that includes animal physiology, nutrition, pathology, mechanical engineering and electronics would benefit the industry in improving catching and hauling conditions.

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CHAPTER 4

Primary Processing of Poultry

INTRODUCTION

SPECIAL large-scale plants for processing poultry are common around the world. These plants are specifically designed to process poultry and include slaughtering, defeathering, evisceration, inspection, chilling and packaging operations. In some cases, they are built adjacent to meat processing plants.

The steps involved in a typical poultry processing plant are illustrated in Figure 4.1; modifications of this arrangement might be seen, but the basic steps are similar in all plants. (Note: another diagram describing the overall operation is provided in Chapter 12.) The operation can be automated to varying degrees, depending on factors such as capital investment, local labor costs and volume required. Some of the modern plants include automated evisceration and cut-up lines that can handle >6,000 birds/hour on a single line, while other manual operations handle only a few dozen birds per hour. Modern equipment, such as computerized machine vision, is finding its way to processing plants and can be used for grading and potentially for inspection purposes (i.e., government agencies in some countries are currently testing this concept). A significant price reduction of various electronic components (e.g., computers, video cameras) has assisted in introducing automated evaluation methods into poultry processing plants. Such methods are extremely helpful when fast-speed lines are required. The information, captured by a machine vision system, can also be used to make decisions about the way each bird will be sold (e.g., whole, cut-up) and even the way it should be cut up (e.g., four, eight cuts) to best match daily market demands. Such computer systems, which can integrate marketing data, are already available, and their use and degree of sophistication are expected to increase.

This chapter will review the different steps involved in the primary processing steps of poultry. Please note that the microbiological and hygienic aspects of the steps described below are further discussed in Chapters 11 and 12.

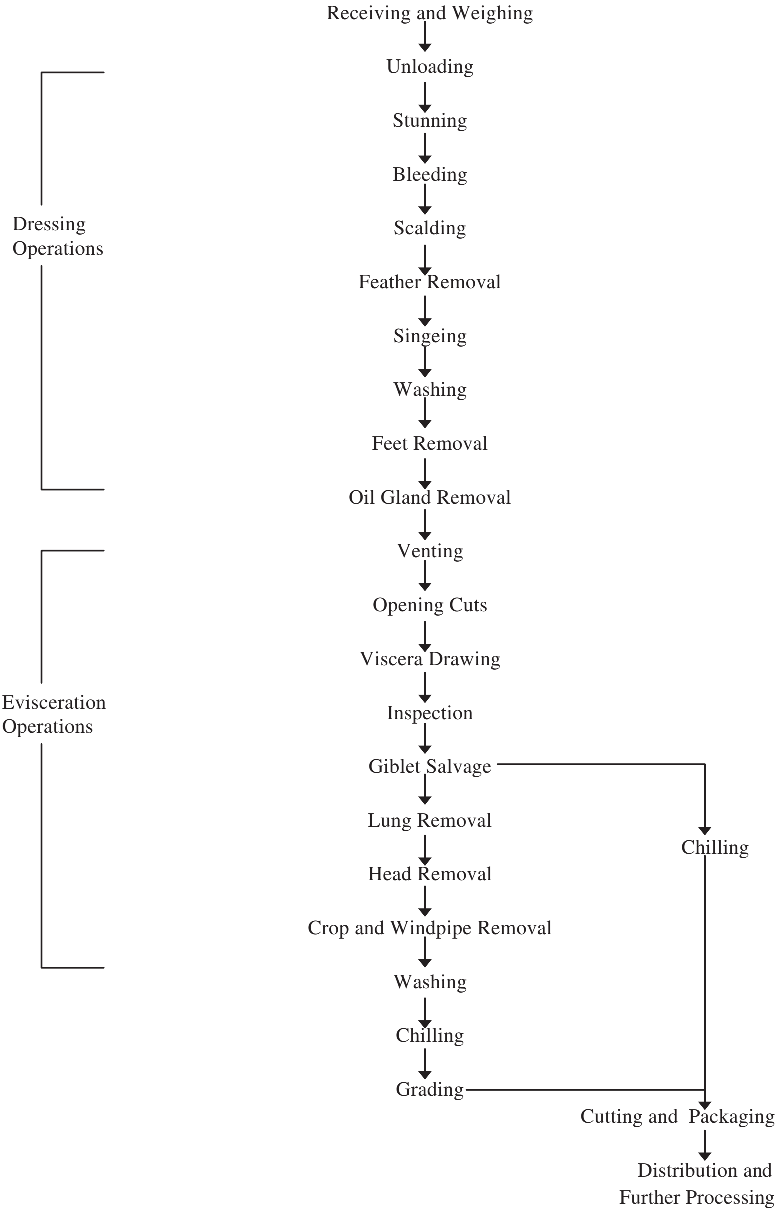

Figure 4.1. *Typical Unit Operations in Poultry Processing.*

RECEIVING AND WEIGHING

This process usually starts with a bulk weighing of the birds received on the truck once the truck enters the processing plant. The live weight is used as the basis for calculating the payment to the farmer. In some countries, the live weight is subtracted from the eviscerated weight (minus the weight of the condemned birds) and, together with the grades assigned, is used to determine the payment to the farmer.

Unloading

Unloading the birds from the crates and placing them on the shackle line is often done manually as seen in Figure 4.2. (Note: the loose crates seen in this figure were described in Chapter 3.) If the crates are built into the truck, the birds can be unloaded and placed directly onto the shackle line by employees standing on a scissor lift. Automated unloading systems have also been developed and are usually part of the modulus crate system (see Chapter 3). In this case, the whole modulus is lifted and tilted slowly so the birds

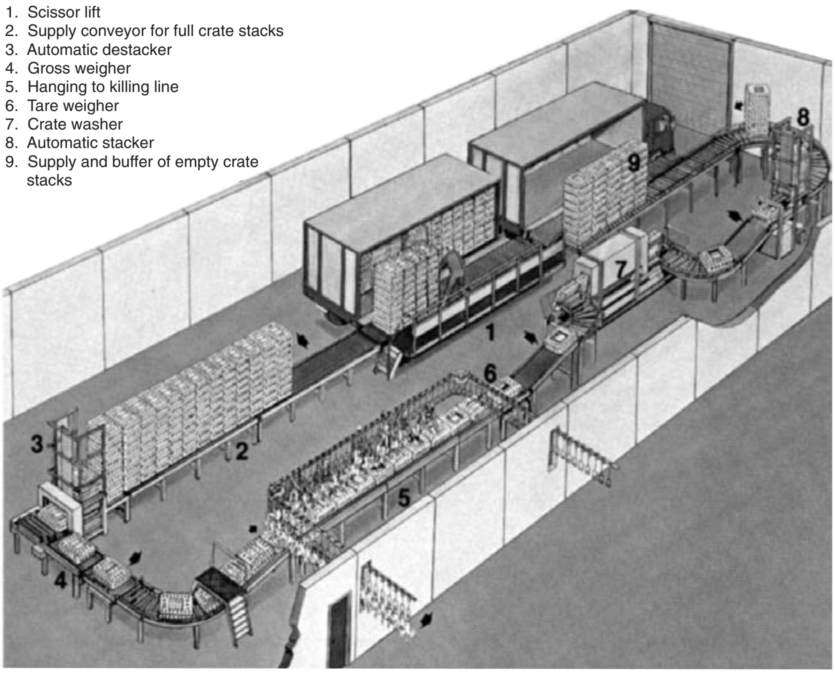

Figure 4.2. *An Example of a Manual Bird Unloading System. Courtesy of Stork PMT Inc., Boxmeer, The Netherlands.*

can walk onto a conveyor belt (Figure 4.3). Because this process is fully automated, motion or light sensors are used to verify that no bird is left in the crate after unloading. If a bird(s) is left behind, the crate can be tilted again, or an alarm is sounded. In plants where gas stunning is employed, the birds can be left in the cages where they are stunned by CO_2, argon gas or their mixture. They are then removed from the crates and placed on the shackle line. This process (described in Chapter 5) helps to significantly reduce bruising of birds taken out of the cages. In this case, unloading should be done immediately after stunning so that no time is allowed for the birds to regain consciousness. Regardless of the unloading operation, special care should be taken to minimize bruising of the birds. Various companies are now investing in measures to minimize the stress birds are exposed to during catching (see Chapter 3), transportation, waiting and unloading. In the latter two phases, measures can include special lighting (mainly blue) that does not excite the birds, special ventilation systems to reduce dust and decreased noise level. Various industry observations and research publications have pointed out that

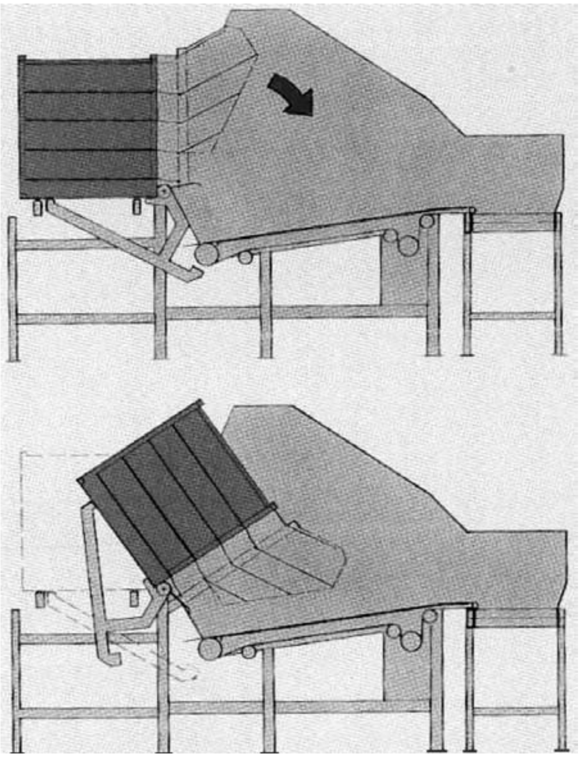

Figure 4.3. *An Example of a Mechanical Bird Unloading System. Courtesy of Stork PMT Inc., Boxmeer, The Netherlands.*

excited birds are more active, flap their wings and are more likely to be hurt during the process (McEwen and Barbut, 1992).

STUNNING

Stunning is common in most plants except when religious considerations are involved (e.g., according to the Jewish and Islamic laws known as Kosher and Halal, respectively). When stunning is used, it can be done by an electrical current, gas or mechanical means. Stunning prior to slaughtering was originally done to immobilize the animal and allow for easier and safer handling of the animal. This was especially true for large, red meat animals. For poultry, immobilization was not as critical for manual slaughtering, but was necessary for the development of automated equipment. More recently, stunning has been used primarily from an animal welfare perspective as a means to minimize the pain and suffering associated with the slaughter process. From this point of view, stunning should produce a rapid onset of stress-free insensibility of sufficient duration to allow the animal to remain unconscious until dead (Fletcher, 1999). Additional information is provided in Chapter 5, which is devoted to the stunning of poultry.

BLEEDING

Opening the blood vessels in the neck (Figure 4.4) results in bleed-out. There are several ways of cutting the blood vessels in poultry. The so-called “Modified Kosher,” which is one of the most common methods, results in cutting the jugular vein just below the jowls so that the windpipe and esophagus remain intact. Leaving the windpipe and esophagus intact is important when automated equipment is later used to pull out the windpipe. Other, but less common, methods include decapitation and mechanical stunning that consists of piercing through the brain and cutting the veins in the roof of the mouth. Overall, the “Modified Kosher” is the most widely used method in modern operations because it is easy to perform (both manually or with automated equipment), results in good bleed-out and leaves the head, windpipe and esophagus intact (Mountney, 1989). Automated high-speed bleeding equipment employs a railing system that positions the neck of the suspended birds in such a way that precise cutting of the blood vessels can be performed. For the real Kosher slaughter, only manual cutting of the blood vessels is allowed. This is done by a specially trained person (called “Shocket”), who cites a blessing during the operation.

The bleed-out phase takes anywhere between 2–5 min, depending on factors such as bird size and type. During the process, about 35–50% of the total blood is lost; however, considerable variation can exist between animals and flocks. Using the Modified Kosher method has been reported to result in

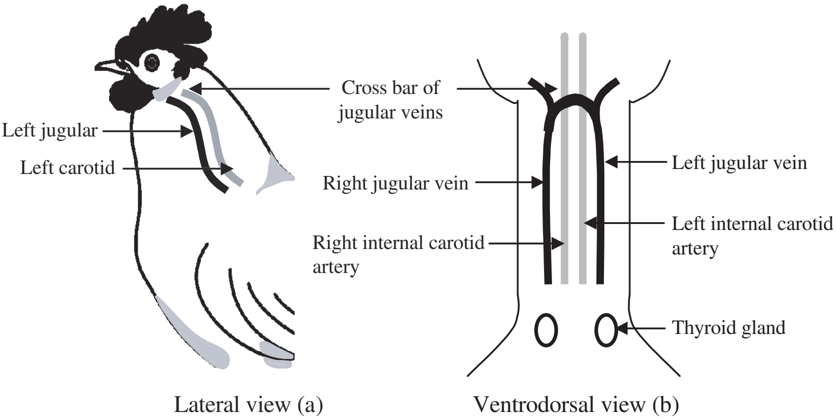

Figure 4.4. *Blood Vessels and the Chicken Neck. Lateral View after Removing the Skin, Muscle (M. longus colli ventralis) and Trachea (a); Ventrodorsal View after Removing the Skin, Muscle (M. sternohyoideus), Trachea and Esophagus (b).*

higher bleed-out than decapitation or piercing (Mountney, 1989). Other factors affecting blood loss include stunning method used and time interval between stunning and bleeding. Table 4.1 demonstrates some of the differences when four stunning methods were employed. Overall, the study showed that bleed-out was significantly affected by stunning method and time of neck cutting. It is important to note that a poor bleed-out can increase the prevalence of carcass downgrading conditions due to blood spots and, in particular, engorged or hemorrhagic wing veins (Gregory, 1989; Gregory and Wilkins, 1989). The data in Table 4.1 indicate that the highest bleed-out was achieved with high-frequency electrical stunning. The 50 Hz, which is commonly used in the United Kingdom, resulted in adequate bleeding when blood vessels were ruptured 1 minute after stunning; a delay of 3 minutes resulted in lower bleed-out. Using a CO_2 + argon mixture resulted in slightly less bleed-out compared to 50 Hz electric current. The bleed-out was not affected by ventral or unilateral neck-cutting methods; however, delayed bleeding resulted in lower values. In the argon stunning, a delay of 3 or 5 minutes did not cause a significant difference. The authors concluded that using CO_2 + argon stunning (currently used in several major plants in the United Kingdom), in comparison with 50 Hz electrical stunning, provided satisfactory results. Additional discussion on gas stunning is presented in Chapter 5.

SCALDING

Scalding is the process of immersing the birds in warm water to loosen the feathers. In a small plant, scalding can be performed manually (i.e., placing the

Table 4.1. Effect of Stunning Methods, Time to Neck Cutting and Blood Vessels Cut on the Bleed-Out in Broiler Chickens. Adapted from Raj and Johnson (1997).

Treatment	Time to Neck Cut (min)	Method of Cutting	Bleed-Out (g/kg) Mean (SE)
Electrical 50 Hz (120 mA)	1	V	34.2 (1.88)^{de}
		U	29.7 (1.74)^{c}
	3	V	26.0 (1.41)^{ab}
		U	28.4 (1.79)^{abc}
	5	V	29.1 (2.19)^{abc}
		U	24.8 (1.33)^{a}
Electrical 1,500 Hz (120 mA)	0.3	V	36.1 (0.93)^{e}
90% Argon	1	V	31.0 (1.56)^{cd}
		U	29.8 (1.11)^{bc}
	3	V	26.5 (1.46)^{abc}
		U	29.8 (1.68)^{bc}
	5	V	30.0 (2.13)^{bcd}
		U	29.7 (1.89)^{bc}
Carbon dioxide + Argon mixture	1	V	30.0 (1.01)^{bc}
		U	28.7 (1.76)^{abc}
	3	V	26.1 (1.67)^{ab}
		U	28.1 (1.50)^{abc}
	5	V	26.0 (1.00)^{abc}
		U	25.0 (0.98)^{a}

$^{a-e}$Means without a common letter differ significantly ($P < 0.05$).

V = ventral cut, both carotid arteries and jugular veins.

U = unilateral cut, one carotid artery and one jugular vein.

carcasses in and removing them from a scalding tank), but in large plants, it is done in a continuous manner employing a single stage or multistage scalding bath while the birds are suspended from a moving shackle line. There are three commonly employed scalding schemes (Table 4.2), and selection of the scheme to employ depends on factors such as the degree of difficulty in removing the feathers, chilling method to follow (water, air) and age of the bird. Higher scalding temperatures are better for loosening feathers from the follicles (see histological sectioning through a feather's follicle in Figure 2.15), but hard scalding is also the most harsh on the skin. In the case of hard scalding, the outer layer of the skin, epidermis (Figure 2.13; see epidermis), becomes loose and is later removed during the plucking operation, where rubber fingers are used to rub the skin. The removal of the epidermis can result in the skin becoming discolored if dehydrated during later air chilling. However, hard scalding is the only satisfactory way to release the feathers of waterfowl. Generally speaking, hard scalding does not cause as much discoloration in the thick skin of waterfowl as it does in other poultry. A milder treatment of medium scalding or subscalding

Table 4.2. Typical Scalding Schedules for Defeathering.

Technique	Water Temperature (˚C)	Time (sec.)	Used For
Hard scalding	59–61	45–90	Waterfowl
Medium/subscalding	54–58	60–120	Mature birds
Soft/semi-scalding	50–53	60–180	Broilers, roasters, young turkeys

(Table 4.2) can cause the removal of part of the outer skin layer that leaves the skin sticky; however, it will not result in excessive discoloration if the birds are kept in a moist environment.

Soft/semi-scalding is commonly used for young broilers and turkeys because it does not damage much of the outer layer of the skin, while it still allows for relatively easy removal of the feathers. In all of the scalding procedures, adequate agitation of the water and uniform water temperature are essential to ensure good feather removal. To improve meat hygiene, careful scalding equipment design is required. Because one gram of soil material (e.g., dirt, fecal material) attached to the feathers can contain 10^8–10^9 microorganisms per gram, it is important to minimize cross-contamination in this common bath. Maintaining and controlling the temperature is one of the key features to keep bacteria load under control. Another means is the use of a counterflow design. The design results in clean water being introduced at the exit end of the tank and water flow toward the entrance where the more contaminated birds are introduced. In addition, installing a multistage scalding tank operation can further reduce contamination problems. In a multistage operation, which can include 2–4 water baths (see Chapter 11; Figure 11.13), the carcasses are moved from the initial, more contaminated bath, to the cleanest bath at the end. The scalding operation is a high-energy and high water consumption process. Some new designs on the market feature energy-saving and reduced water consumption options. In a true Kosher processing, scalding is prohibited. This usually results in more visible skin tears because additional force is required to remove the feathers.

FEATHER REMOVAL

In large processing plants, feather removal is done by mechanical pickers/pluckers equipped with rubber fingers that rub the feathers off the carcass. In a continuous operation, this is done while the carcass is hanging upside down and moving forward (i.e., carried by a shackle line) in between two/three sets of drums or disks covered with rubber fingers. Figure 4.5 shows two com-

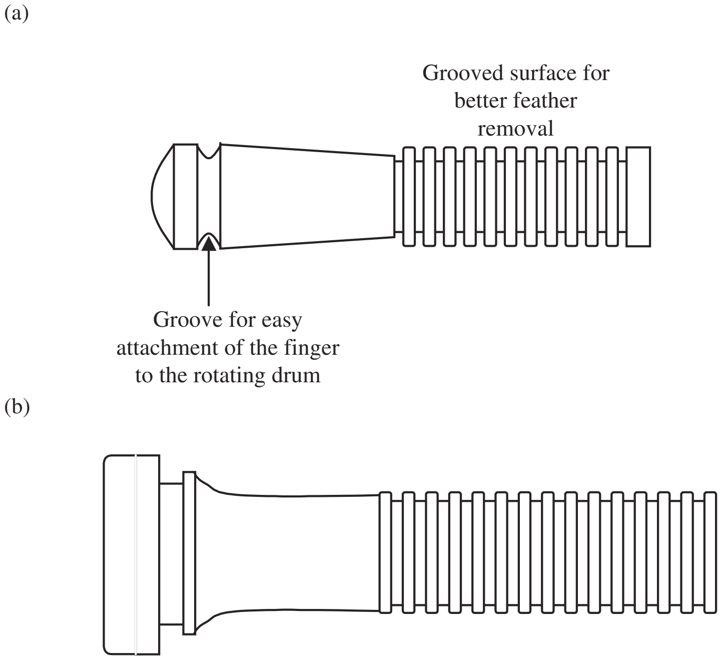
(a)
Grooved surface for better feather removal
Groove for easy attachment of the finger to the rotating drum
(b)

Figure 4.5. *Typical Rubber Fingers Used for Picking/Plucking Poultry Feathers. A Short Finger of about 9 cm Long and 1.5 cm Diameter (a); and a Longer 12 cm Finger with a 2 cm Diameter (b).*

mon finger designs. The fingers are made out of rubber and contain different levels of a lubricating agent that controls their hardness, elasticity, etc. All of the chemicals/materials used in making the fingers have to be approved for use in contact with food; any modification should be approved by the local regulatory agency. Elasticity and length of the fingers varies, depending on the task required, machine speed, etc. Figure 4.6 shows one arrangement of picking fingers mounted on round disks. The defeathering equipment is composed of a few dozen of these disks, and the carcass is passed between the rotating disks. The fingers can also be mounted on drums that rotate toward the center. The distance between the two sides (Figure 4.6) is adjusted to accommodate size variations.

Figure 4.7 shows the feather follicle distribution on a chicken. Areas of denser feather coverage are shown with more feather follicles. Some of the feathers are more firmly attached and require more force to remove. In order to achieve this task, the rubber fingers should be placed closer to the carcass, or additional plucker disks should be installed at strategic locations (e.g., bottom part shown in Figure 4.6). Buhr et al. (1997) investigated the feather retention force in commercial broilers (Table 4.3). The broilers were electrically

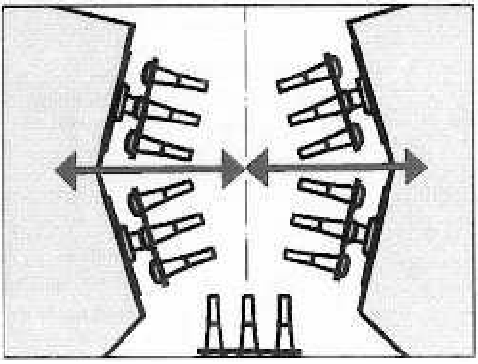

Figure 4.6. *An Arrangement of Disks Used for Plucking Chicken Feathers. Note that the Defeathering Equipment Has a Few Dozen Such Disks Installed, and the Distance between the Two Sides Can Be Adjusted to Accommodate Size Variation. Courtesy of Stork PMT Inc., Boxmeer, The Netherlands.*

stunned (50 V stunner with alternating current, for 10 seconds; average current drawn of 30 mA per bird), bled (severing both carotid arteries and at least one jugular vein) but not scalded. The results show that the force was consistently greater in the femoral area than in the pectoral area, with sternal feathers requiring the least force. The carcasses were either suspended from the shackle line (inverted) or placed on a table (supine).

Klose et al. (1961) have shown that scalding significantly reduced feather attachment. They reported that scalding broilers at 122°F (50°C) reduced feather pulling force by about 30% compared to pulling similar feathers from a live bird. When scalding temperature was raised to 128°F (53°C), force was reduced by about 50%, and when the temperature was set at 140°F (60°C), about 95% reduction was seen. The authors also used an anesthetic drug (sodium phenobarbital) to assist in releasing the feathers. When they measured the force reduction in live birds, they reported about 50% reduction. When they combined the anesthetic drug and scalding, there was an additional reduction below the value of the anesthetic drug alone at the 122° and 128°F scaldings. At the 140°F scalding, the difference was not so great, because scalding already resulted in such a large reduction. The authors suggested that 140°F was too high for broilers and recommended a lower temperature. Buhr et al. (1997) have not used scalding because "it would overwhelm the detection of minor factors as angle of feather extraction, sampling side, stunning, spinal cord severing, or carcass orientation" that they were examining.

The feather follicle distribution in a mature turkey is shown in Figure 4.8. Overall, feather removal force is higher in turkeys and increases as they mature.

In a low-volume operation, the defeathering process can be done in batch-type equipment where the carcasses are placed in a rotating drum equipped with rubber fingers. In small-scale operations, handpicking of the feathers can

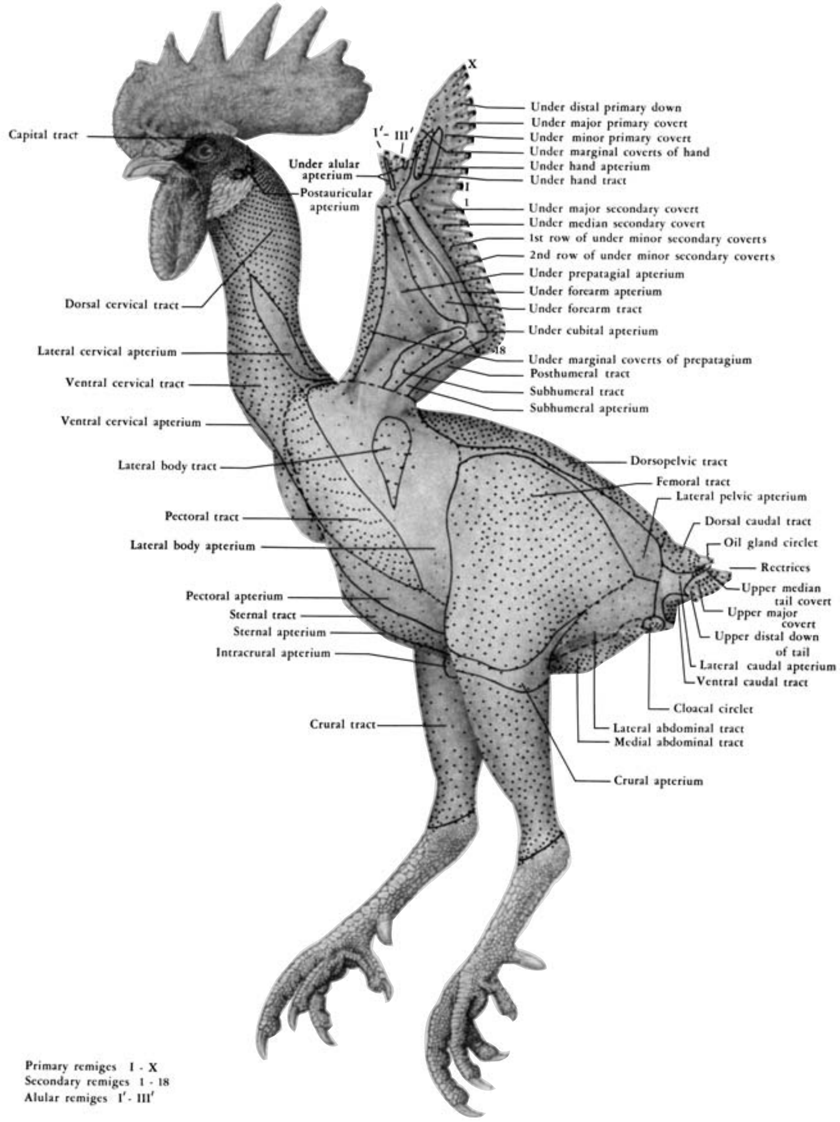

Figure 4.7. *Feather Tracts of a Leghorn Chicken. From Lucas and Stettenheim (1972).*

be seen. Handpicking is also utilized if feather collection is required (see Chapter 15, ornamental feathers, etc.). When pinfeathers are a problem, as with waterfowl, wax dipping is common after mechanical picking. Suspending the carcasses in hot wax, followed by cold water immersion, hardens the wax, which is later peeled in large pieces, pulling off the pinfeathers. The wax

Table 4.3. Feather Retention Force Influence by Carcass Orientation During Slaughter and Feather Sampling for the Pectoral, Sternal and Femoral Feather Tracts. Adapted from Buhr et al. (1997).

		Initial Postmortem[a] (2 min)			Final Postmortem (6 min)		
		Feather Tract			Feather Tract		
Slaughter Orientation	Sample Orientation	Pectoral	Sternal	Femoral	Pectoral	Sternal	Femoral
		(g)					
Supine	Supine	425	311	618	434	338^{bc}	677
	Inverted	423	363	631	424	367^{bc}	649
Inverted	Supine	422	344	667	437	325^{c}	637
	Inverted	380	366	663	405	394^{b}	709
Side							
Left		396	337	632	433	372	667
Right		429	355	657	417	340	669
Pooled SEM		40	37	49	40	41	59
		Probability					
Source of variation							
Slaughter-sample orientation		0.1434	0.0524	0.2337	0.5076	0.0193	0.1570
Side		0.0557	0.2220	0.2402	0.3109	0.0515	0.9532

[a] Postmortem 2 or 6 minutes after stunning and bleed-out. All broilers were stunned inverted on a shackle and bled as indicated.

[b,c] Means within a column and parameter contrast with no common superscript differ significantly ($P < 0.05$), $n = 4$ broilers.

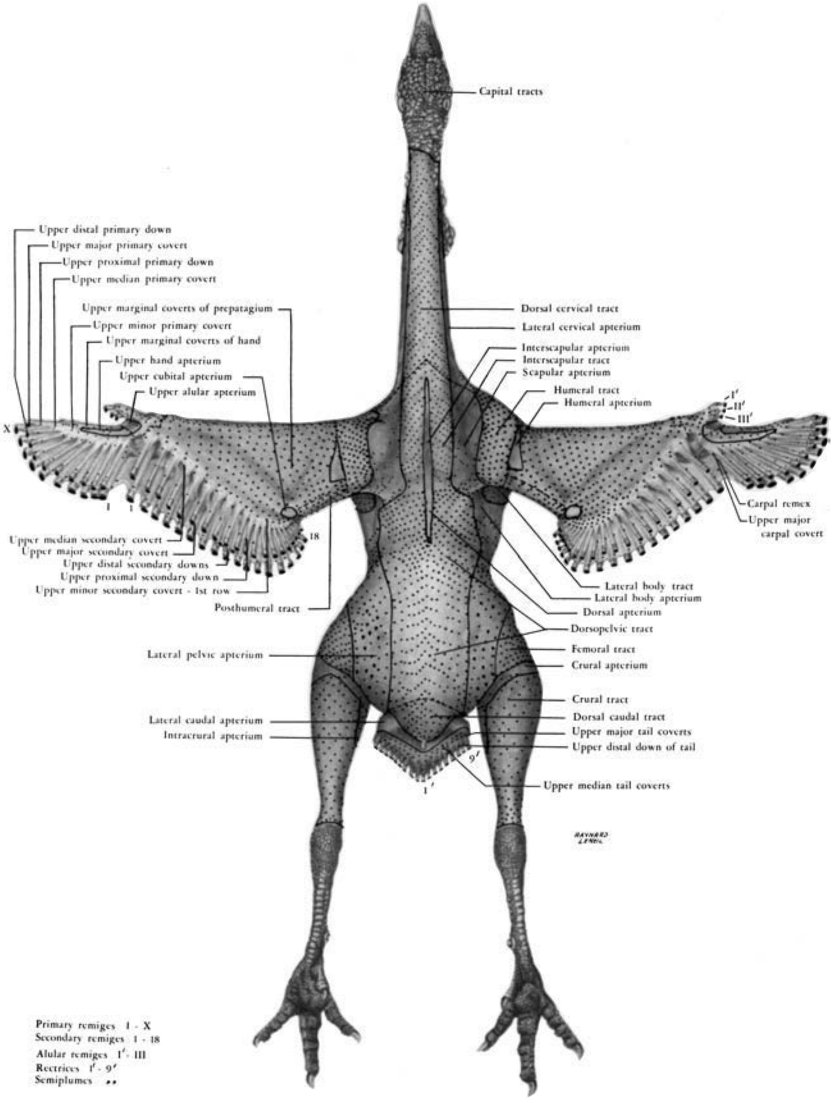

Figure 4.8. *Feather Tracts of an Adult Bronze Turkey; a Dorsal View. From Lucas and Stettenheim (1972).*

can be reused after reheating and filtering the feathers from the previous batch. When only minor problems of pinfeathers exist, singeing (the process of burning small feathers) is commonly used. This is done by passing the carcass through a flame of a "clean" burning substance (e.g., natural gas) that does not leave any off-odors or flavors. The carcasses are then rinsed to remove all the soil left after the defeathering and singeing processes. Rinsing is commonly done using a set of high-pressure spray nozzles to remove the debris from the skin while the carcass is moving on the shackle line. A description of an inside/outside bird wash is provided later in the chapter.

OIL GLAND AND FEET REMOVAL

These steps can be done manually or by automated equipment. In an automated oil gland removal process, a set of metal bars/rails, along the shackle line, position the bird at a certain angle, allowing a rotating blade to cut off the oil gland from the tail area.

Feet removal used to be done manually, but in modern plants, automated equipment is used. The knee joint is positioned, by guiding bars along the shackle line, on an angle and cut off when passing by a circular rotating blade. It is important that the cut be done between the bones and not through a bone because cuts through the bone will appear dark/red in the chilled bird and, after cooking, will turn dark or almost black. Some of the new automated leg cutters first bend the leg then perform a small incision (with a stationary knife) that results in further bending of the leg. The leg is then cut off at the joint with a rotating circular blade. Depending on market demand, sometimes only the foot is cut off (by cutting the hock) instead of the whole leg.

REHANGING

After removing the legs, the carcasses are usually moved to another line. This can be done manually as the carcasses fall onto a sorting table or automatically by transferring the birds to another line. When the birds are initially unloaded from the crates, they are placed on the line with their feet suspended from the shackle. This is the easiest and fastest way of placing the bird on the line. Later, after removing the feet, there is a need to resuspend the birds from the knee joint. Transferring the birds to another line also assists in reducing contamination because the dirty shackles used for the live birds are replaced with cleaner ones. The shackles used for the live birds are commonly washed before being used for the next batch. Devices for a continuous washing operation are available in the market.

An automated rehanging device can consist of a large wheel (carrier) with slots for holding the birds from underneath the knee joints (Figure 4.9) and later pushing them into the evisceration shackle line slots. There are different arrangements available on the market, but the important thing is that the two lines (defeathering and evisceration) be synchronized. This can be done by coupling both drives or establishing a buffer area. Some of the advantages of using automated rehanging equipment include labor savings, better hygiene

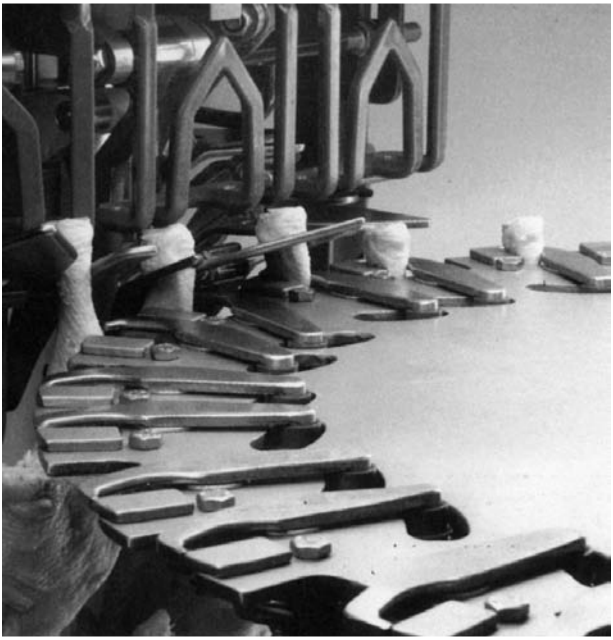

Figure 4.9. *A Transfer Device Used for Automated Rehanging of Birds. Courtesy of Meyn Inc., Oostzaan, The Netherlands.*

because not all of the birds are piled on a sorting table and a more even rigor mortis process. The latter can be important because, at this stage, rigor starts to set in (see Chapter 2), and by rehanging without any delay, all birds are positioned the same way (i.e., equivalent tension on similar muscles) and, therefore, no deformation takes place.

EVISCERATION

In this process, the body cavity is opened and the viscera is withdrawn (Figure 4.10). This process can be done manually using a knife and a pair of scissors or semi-automatically or fully automatically using a circular cutting blade and a scoop-like arm to withdraw the viscera. The latter is done on high-speed lines (i.e., 2,000–8,000 birds per hour). In all cases, special care should be taken not to pierce the viscera and contaminate the carcass. Such a contamination can result in exposing the meat to high microbial loads (i.e., 1 g of gut content can carry 10^9 bacteria). In some countries, such a contamination results in condemnation of parts or the whole bird exposed to the spill, whereas in other countries, washing of moderately contaminated carcasses is permitted.

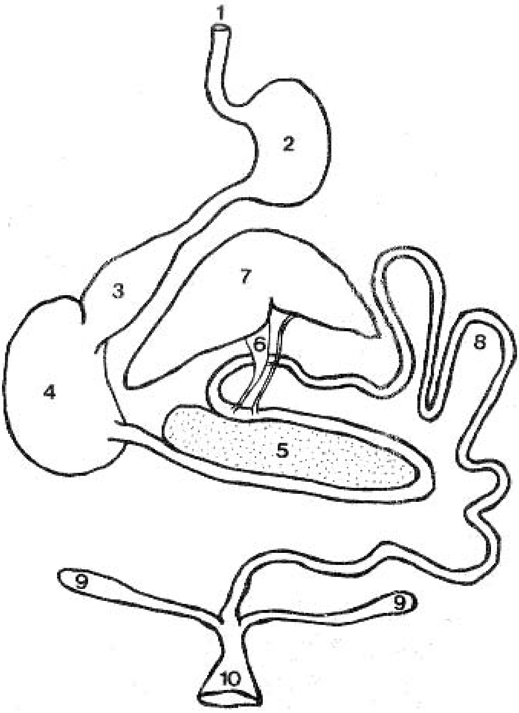

Figure 4.10. *Alimentary Tract of Poultry: (1) Esophagus, (2) Crop, (3) Pro Ventriculus, (4) Gizzard, (5) Pancreas, (6) Gallbladder, (7) Liver, (8) Small Intestine, (9) Cecum, (10) Cloaca. From Swatland (1994). With Permission.*

In a conventional manual operation, the abdominal skin is cut open along the midline (anterior part of the breastbone toward the cloaca), while the skin around the cloaca is usually cut in a circular pattern to minimize the chance of gut content spilling on the carcass. It is useful to read the description of Childs and Walters (1962) for a manual process: "The evisceration is performed by supporting the bird with one hand and inserting the fingers of the other hand through the incision in the abdomen. The three middle fingers (and sometimes the middle finger) extended, slide past the viscera until the heart is reached. They are then partly closed in a loose grip followed by a gentle twisting action, and the viscera are slipped out of the body and released." The same basic steps are used today when automated equipment is employed. The mechanization of the process requires precise control of the different operations/moves. Adjusting the equipment to accommodate variations among flocks (e.g., bird size) is of great importance because unadjusted equipment can result in ripping of the intestines, causing gut spills and damaging the carcass. Because current equipment is not designed to adjust itself (i.e., no sensors to gauge pressure or X-ray

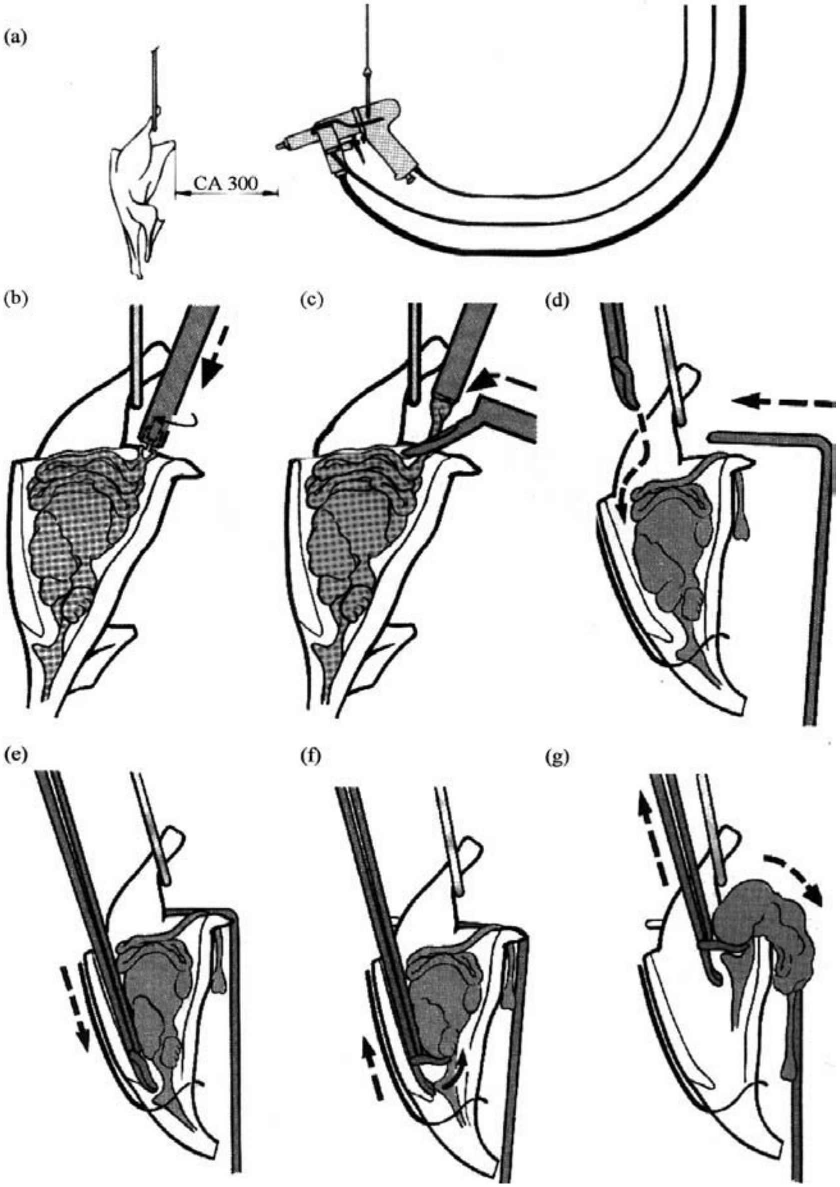

Figure 4.11. *Examples of Semi and Fully Automated Evisceration Processes: (a) Vent-Cutter Gun Operated by Plant Personnel, (b to g) Automated Vent Cutting, Showing (b) Positioning of the Carcass, (c) Pulling the Cloaca, (d) Positioning the Carcass Prior to Evisceration, (e) Inserting the Drawing Arm, (f) Opening the Drawing Scoop, (g) Pulling Out the Viscera Pack. Courtesy of Stork PMT Inc., Boxmeer, The Netherlands.*

mapping of bone location is employed), the eviscerated birds should be monitored on a continuous basis. It should be mentioned that X-ray or other mapping devices start to appear in red meat cutting, where larger variations among animals can be expected and where line speeds are much slower (i.e., by a factor of at least 100). Generally speaking, a poultry eviscerating line is usually designed to handle only one specie (e.g., chicken, turkey).

In semi- or fully automated evisceration processes, the first step is to cut around the cloaca, using a circular rotating blade [Figure 4.11.(a)]. The vent

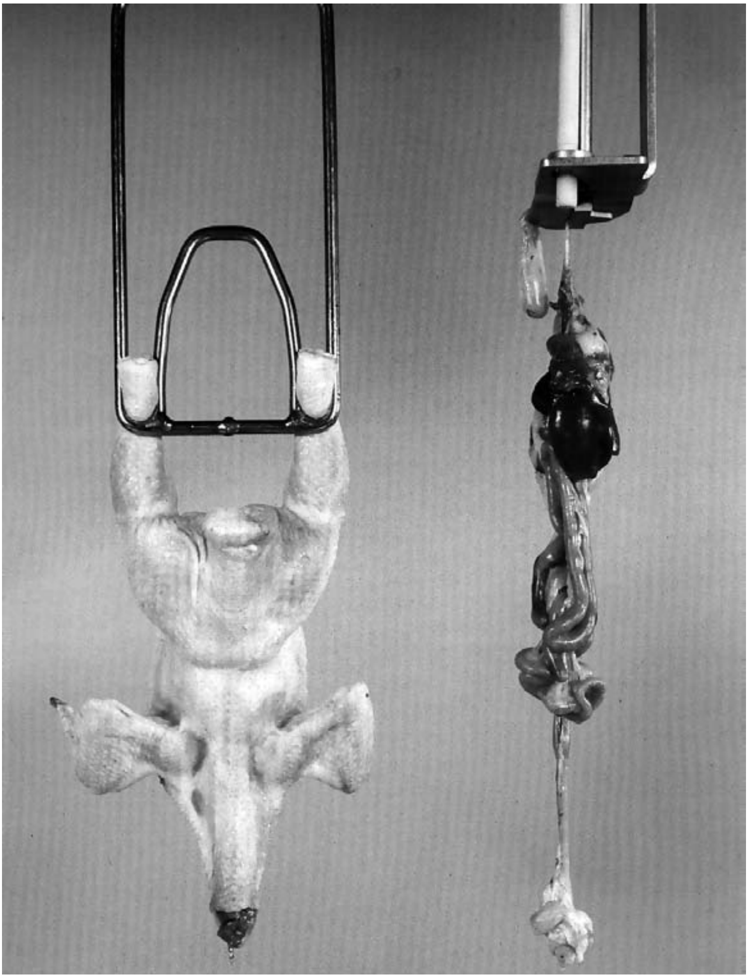

Figure 4.12. *Viscera Separated from the Carcass during the Evisceration Process and Presented Together with the Carcass for Inspection. Courtesy of Stork PMT Inc., Boxmeer, The Netherlands.*

cutter is manually operated and should be precisely placed around the cloaca. The blade diameter should match the size of the particular bird being processed. Some of the new devices are equipped with a vacuum device to reduce potential fecal contamination. The cutting head is commonly rinsed after each insertion [see Figure 4.11.(a), one of the three lines is a water line]. The steps involved in a fully automated evisceration process are shown in Figure 4.11.(b–g). Correct positioning is very important in minimizing potential damage to the viscera pack and the carcass. In some operations, the carcasses are rinsed after withdrawing the viscera.

In conventional semi- or fully automated lines, the viscera is withdrawn from the body cavity but remains attached to the body for inspection purposes. Some of the new automated equipment currently on the market allow total viscera separation right after its withdrawal (Figure 4.12). This step can further improve the cleanliness of the eviscerated carcasses. In addition, the carcasses can also be rinsed prior to inspection. If the viscera pack (i.e., intestine, liver, gizzard and heart) is detached from the carcass, it should be identified and inspected together with the carcass from which it was removed. This requires precise synchronization of the carcass and the viscera lines. Once the viscera pack is exposed/removed, the birds are inspected.

INSPECTION

The inspection is done at this point because the inspector can see all parts at the same time. The attached or detached viscera (Figure 4.12) can reveal diseases/problems with the internal organs. Inspection requirements differ among countries (see Chapter 6), but the inspection is usually carried out by a government official. This process is essential in ensuring that only wholesome birds, free of disease, will get to the marketplace. In some countries, it is required that each individual bird be inspected by a qualified veterinarian, whereas in other countries, inspection is done on a whole-flock basis, and only a certain number of individual carcasses are inspected by a trained inspector. The inspection area should have adequate bright light (conditions usually specified in the local Meat Inspection Act), a hand-washing station, a rake for placing suspected birds and a bin for condemned birds. The suspected birds can later receive a more thorough inspection, and all or parts can be salvaged. Line speed should be adjusted so that the inspector can check every bird. If the line speed is too fast, more than one inspector can be standing by the line. Another common practice is to divide the flow over a number of stations so no confusion arises as to which bird should be inspected by whom. In any case, the carcasses should be presented in a clear way, and sufficient spacing among birds should exist. Often, a mirror is installed on the back side, so the inspector can view both sides without having to touch the product.

Some equipment manufacturers are currently evaluating computer vision systems to assist and alleviate the pressure associated with examining a high-speed line. The system captures a digital picture of the carcass and compares it with a reference. Any deviations are flagged as suspect and can receive a thorough inspection. Some systems employ "fuzzy-logic" that allows them to "learn" over time by introducing new variables.

GIBLET HARVESTING

The viscera is removed after inspection, and giblets (liver, heart and gizzard) are salvaged and washed in a separate line. This is an optional step, where sometimes none or only some of the organs are harvested (i.e., depending on market demands). In the past, the process was 100% manual; however, today, the process can be semi- or fully automated. The gizzard (stomach used to grind the food because birds have no teeth) is first cut open, then the content is removed and the lining is peeled off. Mechanical equipment used for peeling consists of two rollers (Figure 4.13; one left- and one right-handed). The equipment can be operated by a person holding and pressing the gizzards onto the rollers or by automated equipment. The gizzards are then inspected, washed and immediately chilled. The hearts and livers are collected, inspected, washed and chilled. The chilled giblets can then be packed in a paper bag (sometimes the neck is included) and inserted back into the eviscerated whole bird, collected and sold in bulk, or used for further processing.

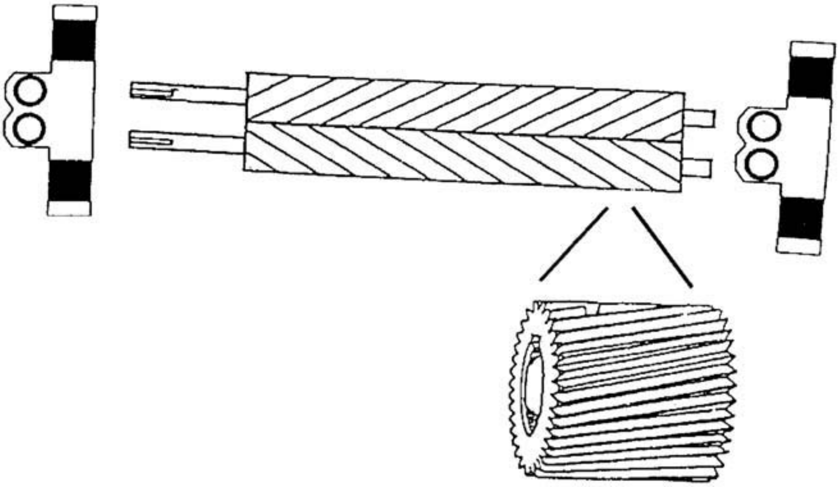

Figure 4.13. *Schematic Diagram of a Machine Used for Gizzard Cleaning, i.e., Pulling of the Lining. Courtesy of DeLong Inc., Dry Branch, GA, U.S.A.*

LUNGS, HEAD AND CROP REMOVAL

The lungs, head and crop are commonly removed after inspection; however, in some operations, one or all of these organs are removed prior to inspection. The lungs can be removed manually using a rake-like device that is inserted into the abdominal cavity. A semi-automated process usually relies on a vacuum gun that is inserted, by a plant employee, into each bird passing on the shackle line. If line speed is too fast for one person, two or more employees can be standing at this station. The vacuum gun looks similar to the vent-cutter gun shown in Figure 4.11.(a); however, it may be larger in size. The vacuum gun is usually suspended from the ceiling, with a tension cord, so the people working in this station do not have to carry its weight all of the time. A fully automated process employs the same type of equipment, but the vacuum gun is inserted by a machine after the carcass has been placed at a certain position. Also, in this case, proper equipment adjustment is critical in obtaining a high-quality product in terms of leaving no residues. Head removal can be done manually using a knife or a pair of shears. Shears operated by air pressure can be used to reduce the stress associated with repetitive motion. The shears can be suspended from the ceiling (similar to the vent cutter and vacuum gun) to further improve working conditions. Automated systems usually consist of a head puller. The device first positions the heads of the carcasses (suspended from the moving shackle line) inside a trough-like structure. This can be done with a guiding rail structure and the assistance of a worm screw device that rotates inside the trough. While the carcass is moving forward, the head is pulled and breaks at the weakest point between the atlas and the axis vertebrae. The advantage of this device is that the esophagus and trachea (windpipe) can also be pulled out gradually and removed from the carcass. This combined process saves a substantial amount of labor. As mentioned before, care should be taken not to damage the esophagus and windpipe during the bleeding operation if this process of crop and windpipe removal is to be employed.

INSIDE/OUTSIDE BIRD WASH

There are various devices that can be used at different points along the processing line to wash the birds. One of the most common points is prior to chilling. An example of an inside/outside bird wash is shown in Figure 4.14. The device has multiple spray points that cover the outside of the product. The spray heads are positioned at critical areas to ensure removal of any debris or blood clots. The inside is washed using a retracting shaft equipped with high-pressure nozzles that spray the abdominal cavity. Tilting the carcass, as shown in Figure 4.14, assists in thorough draining of the water

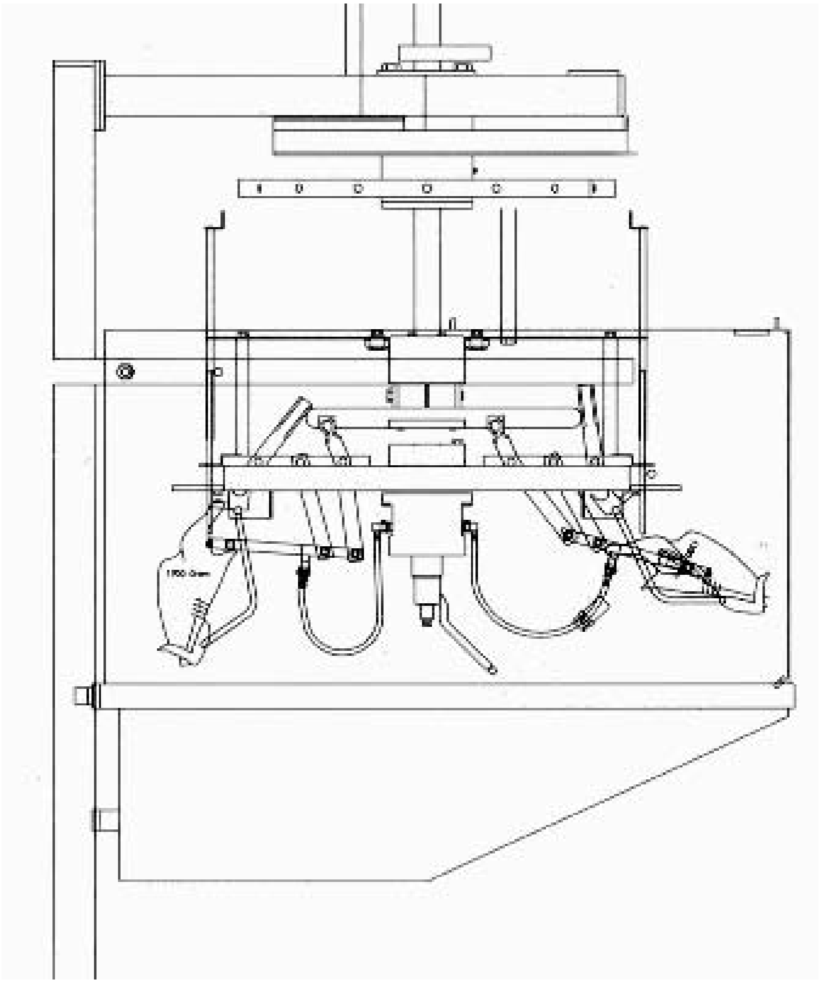

Figure 4.14. *Inside/Outside Bird Wash. Courtesy of Baader/Johnson Food Equipment, Kansas City, KS, U.S.A.*

through both the abdominal opening (created during evisceration) and the neck opening (formed after pulling the windpipe and the crop). Different variations of washers are found on the market and can be used for inside and outside rinsing after evisceration or outside washing after the defeathering process (i.e., prior to evisceration). Such rinsing helps to remove any debris left on the carcass after scalding, feather removal and evisceration. High-pressure, low-volume nozzles can be effective in removing such debris, where proper positioning is very important in the efficient removal of debris. Some designs have spray heads positioned along the moving shackle line, washing first the upper part of the carcass and gradually the lower parts. Where permitted, bactericidal rinses, such as chlorine and organic acids, can be used. Chlorine, in levels up to 20 ppm, is one of the most commonly used chemicals (where permitted). Bactericides, such as organic acids and phosphates, are more commonly used prior to chilling. See additional discussion on the different bactericides in Chapter 11, including Figure 11.15.

CHILLING

The meat must be quickly chilled to minimize microbial growth. This step is mandatory in most countries, but where it is not, it is recommended that chilling take place as soon as possible. The most common methods include water-immersion chilling, air chilling and spray chilling (which includes air and water). For immersion chilling, it is common to use long chillers with a counterflow of cold water, sometimes supplemented with crushed ice, to bring the carcass temperature to about 4–5°C within 30–75 minutes. The carcasses are dumped into a trough-like structure that usually contains a large diameter auger that moves the birds forward (Figure 4.15). Another design employs large paddles that move the product slowly forward. Parallel flow chillers (i.e., product and water flow in the same direction) and chillers with cold water added along the chilling tank are still used in various plants. However, the most common design used today is the counterflow design, where the product moves counter to the flow of the cold clean water. This is a more efficient way of cooling the carcasses (i.e., coldest temperature at the end of the tank) that also assists in improving hygienic conditions. The microbial quality of birds coming out of the water chiller is usually better than before chilling; the chilling system allows for the washing of some bacteria (see Chapter 11). The chilling tank length and diameter are determined by the product flow requirements. The average dwell time is 30–40 minutes, but dwell time can be changed by slowing down or speeding up the auger movement. To increase cooling efficiency, agitation and turbulence are used. A simple and economical way of achieving turbulence is by blowing low-pressure air into the tank at various points at the bottom of the tank. The amount of air can be adjusted to increase/decrease mixing. It is important to remember that only clean air, preferably from outside of the plant, should be used.

The use of a pre- and a post-chiller is another improvement in obtaining a cleaner product. In the pre-chiller, fresh water is used for the initial chilling and washing of the carcasses. A counterflow design assists in the removal of blood and small pieces of loose tissue from the product that is moving toward cleaner water. The product is then lifted, drained and passed into a post-chiller, where clean, cold water is used to further cool the product. Ice can be added at different locations, but is usually added toward the second half or

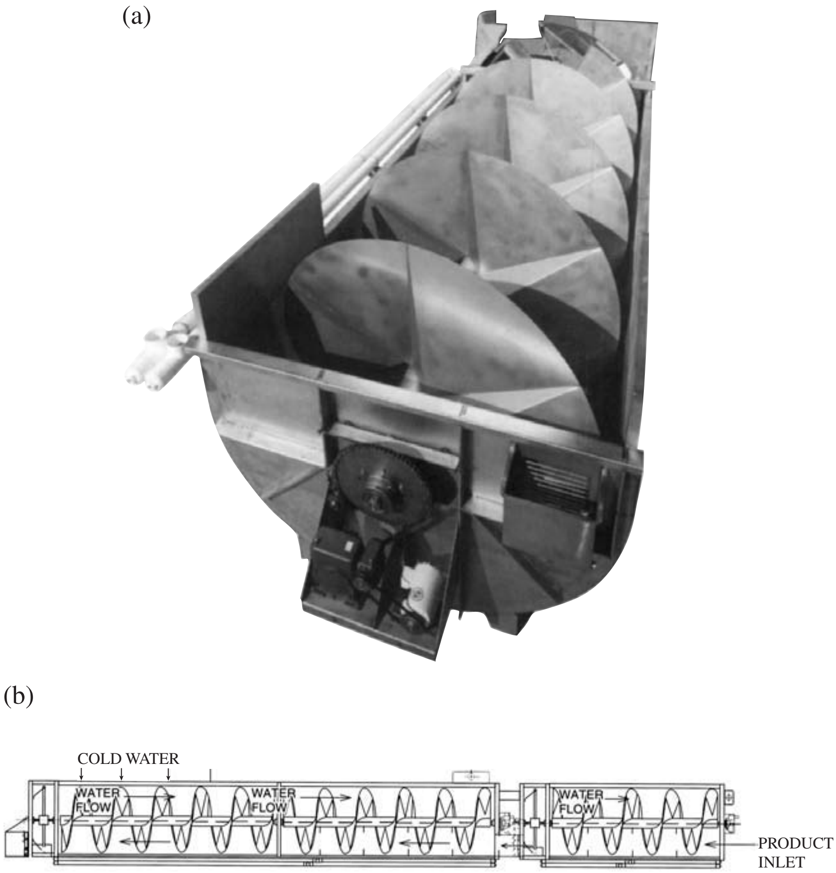

Figure 4.15. *A Water-Chilling System (a) Using a Counterflow Cold Water Stream (b). Courtesy of Morris Inc., Raleigh, NC, U.S.A.*

the end of the chilling tank. The amount of water overflow in the chilling tank is regulated in some countries. Table 4.4 shows the minimum amounts required by the European Union.

The product emerging from the chiller is allowed to drip for a few minutes so that excess water will come out. In many countries, the amount of water picked up during the chilling process is regulated and is based on a certain percentage of the body weight. Table 4.5 shows the maximum amount of water pickup allowed in the United States. In Europe, the EU regulation (#1538/91 EEC) is based on chilling methods and specifies maximum values for air chilling—1.5%, spray chilling—3.3% and immersion chilling—5.1%.

Air chillers are commonly used in Europe, but they are starting to appear in North America and elsewhere. Cold air is used as a chilling medium, so care

Table 4.4. Amount of Water Overflow in a Water Chiller According to the EU Regulation.

Bird Eviscerated Weight (kg)	Minimum Water (L)
≤2.5	2.5
2.5–5.0	4
≥5.0	6

should be taken not to dry the product surface. This is usually achieved by increasing the air humidity (which also improves heat transfer) and/or wetting the product at some point(s) along the chilling process. By doing so, dehydration losses can be reduced to about 1%. A typical setup includes an overhead railing system that goes back and forth along the chilling tunnel/room; the overall railing system can stretch to a few kilometers. Air is blown over cooling elements and then circulated around the room at a fairly high speed. Depending on the chilling tunnel capacity and volume of the product sent through, chilling can be achieved within 60–150 minutes. An improvement of the process includes a system that directs cold air into the abdominal cavity of the carcass and onto the exterior of thick parts (e.g., breast, leg). This process can shorten the chilling time and improve the efficiency of the system. Advantages of using air chilling are no moisture pickup and a drier final product that does not show much exudation (drip loss) when packed in trays. Some processors also claim that the microbial quality of the product is better than that of a water chilled product, but that is usually not the case (see Chapter 11).

Spray chilling is a hybrid between water and air chilling. Cold water is constantly sprayed over the carcasses while they are moving on a shackle line. Moisture pickup is less than during water chilling, but it is higher than during air chilling.

Overall, choosing one chilling method over another depends on many factors. Among the key factors are market demand, water cost and availability,

Table 4.5. Allowed Water Pickup Levels, During Water Chilling, in the United States

Type	Moisture Allowed[a]
Turkey >20 lb	4.5%
Turkey 10–20 lb	6.0%
Turkey <10 lb	8.0%
Chicken <4.5 lb	8.0%
All other kinds and weights	6.0%

[a] Based on ready-to-cook carcass weight.

electricity costs and capital investment available, all of which are beyond the scope of this book. Overall, it is recommended that the processor consult with equipment manufacturers, inspection personnel and consumer groups in order to make the best decision for its region.

WEIGHING, GRADING AND PACKING

After chilling, the birds are usually weighed, graded and later packed or deboned for further processing. In most large plants, automated weighing equipment connected to a computer network is used to record the weight of each carcass. Some more sophisticated computer systems can also make a decision about the best way to market each bird (e.g., whole carcass, parts). The decision depends on input regarding market demands for a specific day/week, requirements for in-plant meat supply, current market prices for various parts, etc. Such a process can be cost effective in high-volume plants that process hundreds of thousands of birds per day.

Grading is done either before or after weighing. It should be noted that grading is usually not mandatory but is done in most large markets to facilitate sales. Grading can be done by a qualified person or with the assistance of a computerized machine vision system. See detailed discussion on grading criteria in Chapter 6. Overall, the final grade and overall meat quality can be affected by different processing parameters (e.g., stunning, chilling) and various feeding, growing and transporting parameters described in this and other chapters.

OPTIONAL TREATMENTS—ELECTRICAL STIMULATION

This is an optional process in which a current is applied to the carcass shortly after slaughter to trigger muscle contraction and speed up postmortem metabolic changes. Overall, the process is much more commonly used by the beef industry than by the poultry industry. The beef industry has been using it for the past 30 years in order to minimize toughening associated with cold shortening and connective tissue in older animals. The process allows the so-called accelerated-processing or hot-deboning in red meat animals and shortens the required 12–24 hour waiting period prior to the completion of the rigor mortis processes (see discussion in Chapter 3 regarding cold shortening and the effect of electrical stimulation).

Electrical stimulation was initially tested in poultry in the early 1960s, but for the next 20–30 years, it did not receive much attention. A renewed interest in the area was seen in the late 1990s when a patented process called the Minimum Time Process System was introduced. The patent described a deboning process that allowed harvesting tender meat 24 minutes postmortem. However, a review by Li et al. (1993) indicated that the large variation in test conditions (e.g., voltage, frequency, current, method and time of application) among researchers studying this area provided inconclusive results. Sams (1999) also reported that stimulation applied on-line could provide sufficient acceleration of rigor and would allow deboning right after chilling. Currently, there is interest in accelerated processing (i.e., harvesting tender breast meat immediately after chilling), and there are a number of systems used commercially in the United States and Brazil. The equipment is similar to the equipment used for electrical stunning, where the carcasses, suspended from a moving shackle line, touch a bottom metal plate (a saline solution is used in the stunner but ususally not in the electrical stimulator) and current is passed between the bottom plate and the shackle line. The device is usually capable of delivering up to 500 V (AC) and can be set to pulse at 0.2–2.0 second intervals.

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CHAPTER 5

Stunning of Poultry

INTRODUCTION

STUNNING of meat-producing animals was originally used to render animals unconscious prior to slaughtering. Traditional slaughter practices in North America and Europe are based on Old Testament laws that are still practiced in the Jewish and Moslem religions. Under religious or ritual slaughter, animals must be killed under strict guidelines, many of which are based on solid health and sanitary principles. For example, animals acceptable for food must be killed and not allowed to die due to natural causes, disease or accident. Until fairly recently, commercial slaughter practices were based on such traditional methods and were not subject to intensive animal welfare issues. However, over the past several decades, animal welfare issues have started to influence commercial practices.

Immobilization of animals by stunning was originally performed to allow for easier and safer handling during slaughter. This is especially true for large, red meat animals (e.g., beef) where mechanical, electrical or gas stunning is used. In poultry, for which immobilization was not as critical for manual slaughter, stunning was required for the subsequent development of efficient automated processes. Initially, electrical stunning was developed to render the animal unconscious so that it could be mechanically manipulated to allow for high-speed automated processes. Later, gas stunning was also introduced (Fletcher, 1999). Commercial livestock slaughter in North America, Europe and other parts of the world is now regulated to ensure product safety and humane treatment of the animal. Where conflicts arise with traditional religious-based ritual slaughter, exceptions are usually made. However, one of the major problems in equipment development is the differences in animal welfare standards. This is true not only between regulatory agencies such as in the United States, Canada and the European Union, but also between ethnic, national and religious groups. Overall, there is by no means universal animal welfare ethics.

Currently, the two most common methods used for stunning poultry are electrical and gas stunning. As will be described in this chapter, variations within each method (e.g., use of AC/DC electrical current, different gas mixtures, etc.) exist. Because religious laws (e.g., Kosher slaughtering) often do not permit stunning, that method will also be discussed.

ELECTRICAL STUNNING

Electrical stunning is the most common method used for immobilizing poultry prior to slaughter. The systems developed for poultry are primarily designed to render the bird unconscious long enough to allow automated neck cutting and reduce carcass damage due to slaughter-induced struggle and convulsions during bleeding. The equipment is relatively inexpensive, simple to use, does not require much space, is compatible with current kill-line speeds, and is usually easy to operate and maintain (Bilgili, 1999). However, proper adjustment of currents by plant personnel can sometimes be a problem. Overall, there are different models of electrical stunners on the market, but their design are fairly similar. Usually, a fiberglass brine/water bath (or any other nonconductive material that is resistant to salt) is fitted under the overhead shackle line from which the suspended birds are moved forward. The bath/cabinet is filled with water or brine solution (usually 1% salt is recommended) to transmit the electrical current. The bath can be vertically adjusted to the height of the birds in order to assure that the heads of the birds are fully immersed in the brine. Stunning is accomplished by passing a sufficient amount of electrical current through the bird for a given amount of time. The state of unconsciousness results from inhibiting impulses from both the reticular and the stomatal sensory systems (see later electroencephalogram data). The stunning current reaching the brain must be adequate to induce an epileptic seizure. The current is usually lower than that required for ventricular fibrillation and, hence, death by electrocution. Insufficient current may physically immobilize the bird but may not prevent perception of pain and stress. Therefore, an adequate level of electricity should be used (adjusted to bird size and number), followed by rapid bleeding so birds will not regain consciousness. In order to apply the current, an electrical metal grate is submerged in the bottom of the brine bath and extends the whole length of the bath. The shackle line is connected to earth, where a ground bar connects the line to complete the electrical circuit. The birds pass through the stunner in a continuous procession (e.g., 140–180 birds per minute in a modern processing line). When the voltage is applied between the submerged electrode and the ground, the current flows through the bird's body. In this way, the birds on the shackle line represent a series of resistors connected in parallel. The amount of current that flows through each bird depends upon the voltage applied, the electrical impedance of the bird and the number of birds. It has been shown that the resistance of broiler chickens ranges between 1,000 to 2,600 Ω (Woolley et al., 1986). As birds enter and leave the stunner, they constantly change the total resistance of the system. At a given constant voltage, the birds receive a current proportional to their own resistance.

Some stunners on the market provide a choice of using low or high frequency, alternating or direct currents, half or full rectified and constant or pulsed currents. The effectiveness of the stunner depends not only on the electrical variables, but also on biological factors that determine the bird's impedance such as weight, composition, sex and feather cover. Therefore, research and development in this area has focused on defining and standardizing the electrical variables used in the process.

Various electrical stunners are used, and they employ different types of waveforms. In a survey done in Britain (Gregory and Wotton, 1987), seven out of the 13 water bath stunners applied a 50 Hz sinusoidal AC [Figure 5.1.(a)]. One stunner used a full-wave rectification of the mains supply [100 Hz; Figure 5.1.(b)]. Square waves [Figure 5.1.(c)] that vary depending on frequency and whether they have a spiked leading edge (usually 280 or 550 Hz) were also used. In addition, fractional sine waves [Figure 5.1.(d)] produced by varying the voltage of the AC current, by introducing a thyristor into the circuit of the sinusoidal AC 50 Hz, was also used. The authors found one stunner that was wired incorrectly, such that the water in the stunning bath was at error potential, and the rubbing bar was live. This stunner was not included

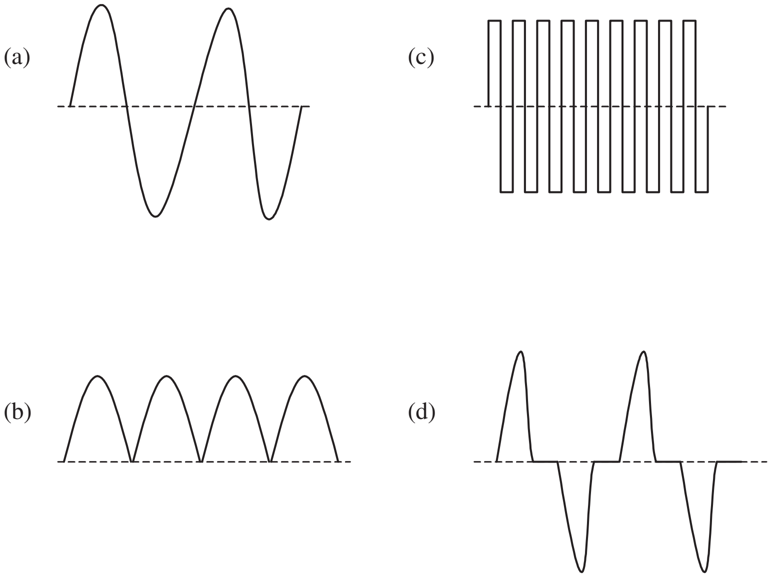

Figure 5.1. *The Main Types of Electrical Waveform Used in Water Bath Stunners. Based on a Survey by Gregory and Wotton (1987) in the United Kingdom. See Text for Details.*

in the study; however, this brings up the point of proper installation, maintenance and monitoring of the operation. In most plants studied, electrical adjustments to the stunner were possible and done to accommodate birds of different sizes. But, sometimes, the equipment was too old or the operator was not qualified/trained to adjust the current. This can result in either under-stunning (i.e., the birds are not sufficiently stunned and rendered unconscious) or over-stunning (i.e., results in high percentage of hemorrhages and broken bones). Overall, the diversity of frequencies and waveforms used made it difficult to recommend a standard current for stunning or inducing a cardiac arrest during stunning. This is especially important when a group of countries such as the EU tries to establish one standard recommendation. Gregory and Wotton (1987) indicated that when they used a 50 Hz sinusoidal AC current, 148 mA per bird was required to induce cardiac arrest in 99% of the broilers. Overall, the minimum current of 120 mA recommended in Europe is based on the fact that this amount of current, when delivered using 50 to 350 Hz, results in sustained loss of somatosensory-evoked responses in the chicken brain. Incidentally, when delivered using a low-frequency current, it also induces cardiac arrest in about 90% of the chickens.

Heath et al. (1994) surveyed the use of electrical stunners in the United States and showed that the low-voltage stunners are the most popular. Out of the 329 poultry plants surveyed, 92% used electrical stunners as a method of pre-slaughter immobilization. The remaining 8% were subject to religious slaughter procedures (e.g., stunning is forbidden according to the Kosher procedure). Low voltage (10 to 25 V) and high frequency (500 Hz) were used in 77% of the plants employing an electrical stunner. The remaining plants reported variation in stunning conditions ranging from 7.5 to 600 V, with no specified waveform (alternating or direct current) reported, and currents ranging from 0.3 to 10 mA. The authors concluded that although there were variations in methods of stunning and slaughter, the majority of plants were in voluntary compliance with the humane slaughter provisions, and the birds were stunned sufficiently to remain unconscious through exsanguinations. It should be pointed out that these low-voltage systems are in contrast to high-voltage and current systems utilized in Europe and other parts of the world. The reason for using higher voltage in Europe is based on reports from the early 1980s that indicated there were problems with electrical stunning of poultry. Some of the reports showed that electrical stunning was unreliable in that approximately one-third of the birds emerged from the stunner dead, whereas another third were unstunned (Health, 1984). Research conducted in the United Kingdom and Germany resulted in European recommendations for stunning with a minimum of 120 mA to instantaneously render the animal unconscious (i.e., a basic requirement in Europe is that electrical stunning should be immediate; <1 second current application to result in unconsciousness) and to effect heart failure such that broilers could not regain consciousness. Therefore, electrical stunning in Europe is considered "high current" and is designed to irreversibly stun (i.e., "stun to death") the bird to assure animal welfare. It should be noted that these recommendations have been based on achieving optimum welfare and are not designed to avoid carcass defects. In the United States, poultry are specifically not included in the legislation covering the humane slaughter of livestock and, as such, stunning conditions are not mandated (Fletcher, 1999). Overall, it is clear from this discussion that there is no universally accepted electrical stunning system. Application of high voltages has been associated with higher incidences of broken bones, damaged viscera, bruised wing joints, red wing tips, hemorrhages on the breast meat, split wishbones and separation of shoulder muscle tendons (Bilgili, 1999). It should be pointed out that sometimes, under commercial conditions, it is very difficult to isolate the effect of electrical stunning from other causes such as catching, hanging, wing flapping, bleeding deficiency and feather picking. Although there is no precise relationship between stunning current and carcass quality attributes, hemorrhages in the deep breast muscle have been clearly shown to increase with high stunning currents. Table 5.1 shows that the prevalence of downgrading tended to be relatively high when currents of 121–161 mA per broiler were applied. High stunning voltages have been linked to increased incidences of red wing tips and broken bones, whereas high stunning current frequencies have been shown to reduce the severity of thigh and breast hemorrhages and to result in fewer broken bones. It is assumed that the causes of muscle hemorrhages in broilers are multifactorial and may involve factors related to live bird production, hanging the birds upside down and stunning procedures. By design, communal stunning baths suffer from a fundamental constraint in that many birds are connected to the same circuitry at the same time. In such a system, theoretically,

Table 5.1. Effect of Stunning Current (50 Hz sine wave AC) on the Prevalence of Carcass and Meat Quality Defects in Broilers (Laboratory Study). Adapted from Gregory and Wilkins (1989a).

	Average Stunning Current (mA)						
Problem	45	85	121	141	161	181	220
Appearance defects							
Red wing tips	7	8	15	16	8	9	9
Hemorrhagic wing veins	4	7	11	16	12	8	9
Hemorrhagic shoulder	12	—	22	23	14	18	13
Hemorrhage in breast muscle	15	10	17	25	23	28	19
Hemorrhage in leg muscle	5	5	4	3	5	4	6
Birds with ventricular fibrillation	21	80	87	99	99	100	100

the current experienced by each bird cannot be precisely controlled. Some attempts have been made to design a constant-current stunner. However, implementing such a system in a commercial slaughter line has been limited. In a commercial line operating at high speed, it is very difficult, if not impossible, to isolate each bird (suspended on shackles approximately 15 cm apart) long enough to determine its resistance and deliver the precise current required.

It is important to note that the stunning, neck cutting and bleeding operations are interrelated. As mentioned earlier, the evolution of the electrical stunners has been, for the most part, influenced by different operations/procedures within the slaughter line (e.g., bleed time, scalding time, extent of automating the evisceration process). Usually, the line speed is dictated by the speed of the evisceration line(s). In the United States, each kill line typically supplies carcasses for two evisceration lines. Depending on the inspection system, evisceration line speeds are limited to either 70 birds per minute (the Streamlined Inspection System) or 91 birds per minute (the New Enhanced Line Speed). For example, a U.S. plant with four New Enhanced Line Speed systems will typically use two kill lines, each processing 180 birds per minute. This is in contrast to European plants, in which each evisceration line is served by a separate kill line, usually operating at 100 to 140 birds per minute (Bilgili, 1999). Thus, it can be seen that the kill-line speed (including dwell time within the stunner) is obviously affected by the later evisceration and inspection operations.

In the past few years, there have been some new developments in the operation of electrical stunners. One example is the low-voltage stunner that operates at 10–14 V, with pulsed direct current, 500 Hz, 10 to 12 mA per broiler (developed in Georgia). The system represents a change in the actual stunning process in which the lengthening of the stunning cabinet (from 1.8–4.2 m) is an attempt to increase the dwell time and reduce the total resistance in the stunner. The cabinet is also equipped with a rump-bar to limit the movement of the birds and prevent them from avoiding the bath. In addition, breast rub pads are installed to calm the birds arriving from the live hanging station. The upper shackle line is sprayed with water or brine to ensure better current flow. The control panels have been redesigned to clearly and continuously display and monitor the voltage and current levels. So, unlike the old stunners, modifying the voltage and frequency is very easy.

GAS STUNNING

Gas stunning of poultry was initially investigated in the 1950s (Kotula et al., 1957), however, it was not considered for commercial use for the next 25–30 years. Only in the 1990s did it start to appear in some commercial plants. It should be mentioned that gas stunning of other animals, such as pigs, has been used for many years. The renewed interest in gas stunning for poultry was triggered by problems related to traditional slaughter practices, which in some cases employ high electrical currents that can increase the rate of hemorrhages and broken bones. The increased demand for cut-up poultry, and further processed products, has also resulted in changing quality assessments such as that meat defects (e.g., broken bones, deep muscle hemorrhages) are more visible to the consumer and are more critical for proper marketing. Because high-current stunning (120 mA, required to address animal welfare issues in Europe) at low frequencies (e.g., 50 Hz) is known to result in higher incidences of broken bones and muscle hemorrhages (Gregory and Wilkins, 1989a), alternatives to electrical stunning were researched in Europe. Table 5.2 shows the effect of using gas stunning (i.e., argon and CO_2) on the reduction of hemorrhages. During the past decade, various studies have examined the effect of gas mixtures on meat quality. One of the approaches evaluated was stunning the birds prior to removing them from the crates and, thus, reducing the damage associated with unloading live birds from crates. Another gas stunning system that employs an automated unloading system followed by a gas tunnel is shown in Figure 5.2. In this system, bruising is also reduced because birds are not pulled out of the crates. Currently, there are five commercial-scale gas stunning systems used in Europe. They operate under a special permit from the European Union Commissioner, because gas stunning is not included in the European legislation. Instead, member states are advised to formulate legislations based on sound science and expert professional advice. Another large operation is situated in Brazil, and a few small, trial-based operations can be found in North America.

Over the past decade, different gas mixtures have been tried. They mainly included various proportions of carbon dioxide (CO_2), argon (Ar), nitrogen (N_2) and oxygen (O_2). Although gas stunning can reduce some of the welfare problems associated with electrical stunning, it is important that the induction

Table 5.2. Average Hemorrhage Scores in Breast and Thigh Meat Related to Different Stunning Methods ($n = 144$). Adapted from Schreurs et al. (1999).

	Average Hemorrhage Score	
Stunning Method[a]	Thigh Meat	Breast Meat
Whole body	3.15 ± 1.17^b	3.56 ± 1.17^b
Head only	2.42 ± 0.94^c	3.07 ± 1.23^c
Argon	2.08 ± 0.96^d	1.75 ± 0.89^e
CO_2	2.07 ± 0.92^d	1.66 ± 0.93^e
Captive bolt	2.04 ± 0.90^d	1.96 ± 0.93^d

[a] Whole body—100 V, 120 mA and 50 Hz for 10 seconds; head only—120 mA, 300 Hz for 1 second; argon—70% Ar + 30% CO_2; CO_2—anesthetic mixture of 40% CO_2 + 30% N_2 followed by an anoxia mixture of 80% CO_2 + 20% N_2; mechanical—captive-bolt device.

[b–e] Means and standard deviations followed by a different superscript are significantly different ($P < 0.05$).

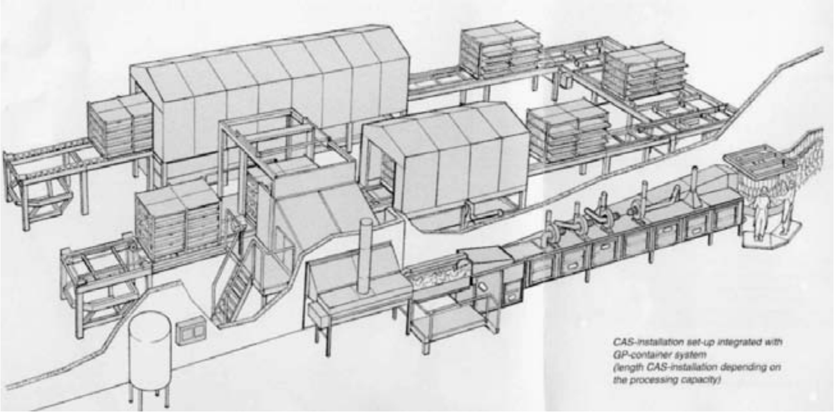
CAS-installation set-up integrated with
GP-container system
(length CAS-installation depending on
the processing capacity)

Figure 5.2. *A Gas Stunning System. Courtesy of Stork Inc, Boxmeer, The Netherlands.*

of anesthesia would not be aversive to the birds and would be induced rapidly. A potential problem is that birds tend to regain consciousness rapidly on exit from the gaseous atmosphere unless they have been killed (Raj, 1998). Overall, there are differences in the initial effect of the gases and, therefore, they should be used in the right concentrations. Argon, for example, is an inert gas that can induce anoxia at a concentration of 90%. Carbon dioxide, on the other hand, is an acidic gas that can be pungent to inhale at high concentrations. The gas is also a potent respiratory stimulant that can cause breathlessness before loss of consciousness. From a welfare standpoint, that means that birds could experience an unpleasant sensation during the inhalation of a high concentration of this gas. Based on the aversive reaction, the use of a high concentration of CO_2 is prohibited in the United Kingdom. In fact, the United Kingdom is the only country to legislate the use of 90% Ar in air or 25–30% CO_2 in air (leaving 2% residual oxygen in both mixtures) for stunning domestic poultry. Raj (1998) indicated that six out of 12 turkeys and three out of eight hens showed aversion to entering a fitting chamber, to obtain feed and water, when it contained 72% and 47% CO_2 in air, respectively. When Ar with less than 2% O_2 was present, six out of six hens and 11 out of 12 turkeys spontaneously entered the chamber. When the chamber contained 30% CO_2, 60% Ar and 10% air, no aversion was seen in 80% of the turkeys entering the feeding chamber. In order to eliminate concern about high CO_2 concentration, a commercial system including two stages (i.e., stunning and killing) was developed (Hoen and Lankhaar, 1999). In the first stage, an anesthetic mixture of 40% CO_2 + 30% O_2 + 30% N_2 is used, followed by a gas mixture employed to induce anoxia that consists of 80% CO_2 + 20% N_2. Results from the system, currently used in Belgium (shown in Figure 5.2), are presented in Table 5.2 (identified as CO_2 stunning). The results for an argon treatment (Table 5.2) represent a system developed in Britain. In that system, a mixture of 70% Ar + 30% CO_2 is used.

Overall, the two gas-stunning methods resulted in significantly lower hemorrhage scores in the thigh and breast meat as compared to the two electrical stunning methods. The captive-bullet stunning, also included in the comparison, caused lower hemorrhage scores compared to electrical stunning; however, this method is not really used on a commercial scale because of various technical limitations, as will be discussed in the next section.

In a single-phase gas-stunning system, birds, still in the cages, are placed on a conveyor belt and carried in to the stunning tunnel. The cages are lowered into a tunnel where the Ar or CO_2 are used (both heavier than air), and the conveyor speed is adjusted to achieve the required dwell time. The tunnel is equipped with various safety devices to protect employees working in the area. In addition, CO_2 and Ar detectors are installed in the room to verify that employees are not exposed to dangerous levels. The cages are then lifted and moved toward another conveyor belt where the birds are deposited. Later, hanging the birds on a shackle line is much easier compared to trying to remove live birds from a cage. The effect of the time between stunning and bleeding is discussed at the end of the chapter.

Another difference between electrical and gas stunning is the rate of postmortem pH decline. Electrical stunning has been shown by numerous researchers to temporarily delay rigor development. Papinaho and Fletcher (1995) reported that stunning current between 0 and 200 mA affected the rate of early rigor development but had no effect on final meat quality. They reported that breast meat pH was higher for electrically stunned broilers compared to gas stunned, and mentioned that electrical stunning is known for its inhibition of glycolysis, up to 6 hours, in broilers. Gas stunning has been found to produce a more rapid pH drop during early postmortem in broiler and turkey breast meat muscles (Raj, 1998); however, after 8 hours, the pH of all of the samples reached about 6.0. The results for glycogen content in the breast muscle showed the same trend of slower glycolysis at early postmortem in the electrically stunned birds. The water-holding capacity (WHC) averages over time (averages were taken because no significant stunning method by time interactions were found) showed that head-only electrical stunning resulted in the highest moisture loss, while the CO_2 stunning resulted in the lowest moisture loss.

MECHANICAL STUNNING

Mechanical means of stunning include concussion, as used in large animal slaughter, or brain sticking with different devices. Because of the welfare and logistical difficulties of positioning the head of the bird at the right point (under automated line conditions), there are currently no commercial systems in use. Overall, the lack of a suitable, fast-operating head-fixing device, which would be required on animal welfare grounds, has curtailed the development of this method for commercial applications. In addition, this stunning method requires suitable restraint of the birds to prevent damages to the carcass that may occur due to severe post-stun convulsions (e.g., severe wing flapping) while the birds are on the shackle line. Using a captive bolt, with adequate head and body restraints, resulted in comparable hemorrhage scores (Table 5.2) to gas stunning. Lambooy et al. (1999) evaluated captive bolt stunning of broilers by using either a pneumatically propelled solid captive bolt (5 mm in diameter and 25 mm penetration depth) or a similarly propelled hollow bolt (needle) that allowed injection of compressed air (2 Atm) into the skull. Although the main objective was to determine the effects of captive bolt stunning on carcass and meat quality, the researchers also evaluated the effectiveness of this type of stunning. They concluded that these devices are acceptable in terms of bird welfare. However, more studies are needed to evaluate whether captive-bolt stunning induces an immediate loss of consciousness and sensibility in poultry species and to determine the effects of physical dimension and velocity of the bolt.

NO STUNNING

According to some traditional slaughter methods, stunning is forbidden by religious laws. According to Jewish and Moslem regulations, called Kashruth and Halal, respectively, animals cannot be stunned and should die by bleeding only. However, it should be mentioned that some Moslem authorities in Western Europe and elsewhere have started to accept high-frequency stunning of poultry, which does not induce cardiac arrest, prior to religious slaughter. Slaughtering without stunning is performed by a trained person using a very sharp knife to cut the jugular veins. During the process, a blessing is cited, and the whole process should be done very quickly to minimize animal suffering (Regenstein and Regenstein, 1979). As mentioned earlier, under these religious or ritual slaughter procedures, animals must be killed under strict guidelines, many of which are based on solid health and sanitary principles. For example, animals acceptable for food must be killed and not be allowed to die by disease or accident. The same principles are used for today's inspection regulations performed by nonreligious government bodies.

STUDYING THE EFFECT OF STUNNING ON ELECTROENCEPHALOGRAM (EEG)

Effect of Electrical Stunning on EEG

EEG has been used experimentally to investigate the effects of electrical stunning on brain function in poultry, pigs and sheep. From that work, standards were proposed for the current necessary to induce electroplectic activity in an animal brain. Overall, these electroplectic activities have two phases, the first being the epileptiform phase consisting of hypersynchronous activity that resembles grand mal epilepsy. The second phase is an electrically quiet or "isoelectric" period. It was suggested that these two phases represent the period of unconsciousness following electrical stunning. Gregory and Wotton (1987) investigated the effects of different stunning methods on the EEG of chickens using a conventional 50 Hz sigmoidal alternating current. Three types of EEG waveforms were observed following electrical stunning when using between 20 and 143 mA per bird. The first was a low-frequency polyspiked activity (<5 Hz) followed by a quiescent phase (Figure 5.3a). The polyspiked activity was taken to be the typical response to a water bath stunning that was seen in 16 out of the 18 broilers stunned. The remaining two broilers showed high-frequency epileptiform activity (approximately 6 Hz) as shown in Figure 5.3b. The polyspike ended abruptly and occurred about 17 seconds (range 8–36 seconds) after the start of stunning. The polyspiked activity was followed by a quiescent phase. It was not possible to quantify the duration of this phase in the experiment because the broilers were slaughtered before normal EEG activity returned. Overall, the low-frequency polyspike activity has been interpreted by the authors as petit mal epilepsy. It is worth mentioning that, in red meat animals, the hypersynchronization of EEG activity leads to high (8 to 13 Hz) activity or grand mal epilepsy.

Gregory and Wotton (1987) also determined the current necessity of causing cardiac arrest when broilers were subjected to electrical stunning with sinusoidal AC at 50 Hz. This was done because it was suggested that electrical stunning, under certain conditions, can induce unconsciousness and fibrillate

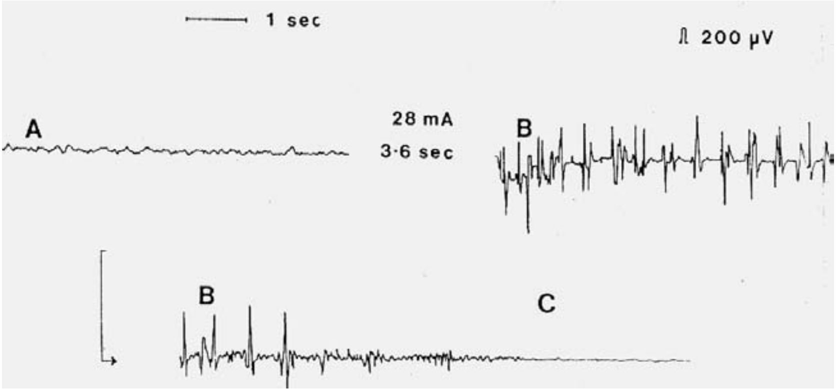

Figure 5.3a. *Electroencephalogram of a Chicken that Developed Low-Frequency Polyspike Activity after Electrical Stunning. A Is a Sample of the Period before Stunning; B Is the Epileptiform Phase; C Is the Quiescent Phase. From Gregory and Wotton (1987). With Permission.*

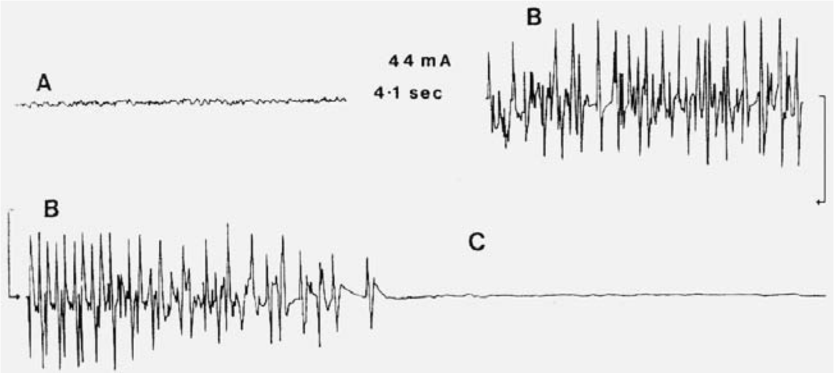

Figure 5.3b. *Electroencephalogram of a Chicken that Developed High-Frequency Polyspike Activity after Electrical Stunning. A Is a Sample of the Period before Stunning; B Is the Epileptiform Phase; C Is the Quiescent Phase. From Gregory and Wotton (1987). With Permission.*

the heart simultaneously. This, in turn, has a potential humanitarian advantage over conventional stunning, which does not cause fibrillation. As fibrillation results in a quicker kill, it does not depend on the automatic neck cutter severing the blood vessels in the neck. They varied the voltage between 50 and 270 V to achieve a range in current applied through the birds (at least 25 birds were used in each of the 30 mA increments). An ECG was recorded immediately after stunning to determine whether there was ventricular fibrillation. On average, the current received by the broilers that fibrillated was twice that of unfibrillated birds. In the broilers that fibrillated, polyspiked activity was suppressed to the extent that the EEG did not always show an epileptiform phase (Figure 5.3c). These attenuated activities occurred in broilers that re-

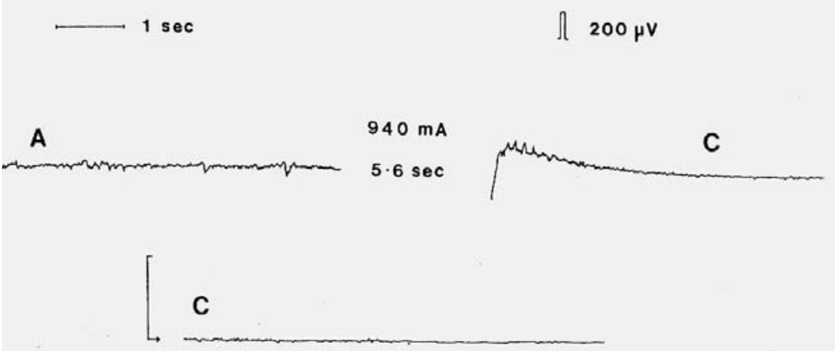

Figure 5.3c. *Electroencephalogram of a Chicken that Did Not Develop Polyspike Activity after Electrical Stunning. A Is a Sample of the Period before Stunning; C Is the Quiescent Phase. From Gregory and Wotton (1987). With Permission.*

ceived high current (>100 mA). Similarly, polyspiked activities were markedly reduced in broilers subjected to head-only stunning when the current was higher than 100 mA. At low currents (30–60 mA), less than 5% of the broilers underwent fibrillation. As indicated earlier in the chapter, the current required to produce fibrillation in 99% of the birds was 148 mA (95% confidence intervals = 132–164 mA). Live weight had no significant effect on the incidence of cardiac arrest. Using high currents was found to have two effects, the first was attenuation of the epileptiform expression. The second was the increase in the likelihood of inducing cardiac arrest. The inhibition of epileptiform activity was not solely due to the induction of a cardiac arrest, because a similar effect occurred when broilers were stunned with comparable currents across the head and, thereby, did not experience cardiac arrest.

Effect of Gas Stunning on EEG

Stunning of poultry with gas mixtures does not result in an immediate loss of consciousness, and, therefore, it is important to ensure that the induction of unconsciousness is not stressful to the birds. Raj et al. (1998) studied the effect of three gas mixtures on time to onset changes in spontaneous EEG and the loss of stomatal sensory-evoked potential (SEP). Exposing the birds to argon resulted in 10 out of the 16 broilers showing high-amplitude, low-frequency (HALF) electrical activity in the EEG, which started about 10 seconds following exposure (Figure 5.4). The other six broilers did not show HALF activity, instead they showed a graduate suppression in the amplitude of EEG signals. The average time to onset of EEG suppression was 17 seconds (n = 16). All of the broilers showed intermittent convulsion after the onset of HALF activity or suppressed EEG. During the convulsive episodes, the EEG showed either epileptiform activity (bipolar, high-amplitude spikes; n = 4), high-amplitude, low-frequency activity (n = 7), polyspike (unipolar, high-amplitude spikes; n = 2) or suppressed (n = 3) EEG. An isoelectric EEG occurred, on average, at 58 seconds after exposure to argon.

During exposure to 30% CO_2 and 60% Ar in air, only one broiler showed HALF activity in the EEG (at 10 seconds). However, all 12 broilers showed suppressed EEG (Figure 5.5), and the average time to the onset of EEG suppression was 19 seconds. All of the broilers showed intermittent convulsions after the onset of EEG suppression. During the convulsive episodes, the EEG showed either epileptiform activity (n = 6), polyspike (n = 4) or remained suppressed (n = 2). An isoelectric EEG occurred, on average, 41 seconds after exposure to this gas mixture.

Exposure to 40% CO_2, 30% O_2 and 30% N_2 for 2 minutes resulted in none of the broilers showing HALF activity, instead, suppressed EEG with low-frequency activity occurred, on average, 40 seconds after exposure (Figure 5.6). Only three out of the 17 broilers exposed to this mixture died; isoelectric EEG

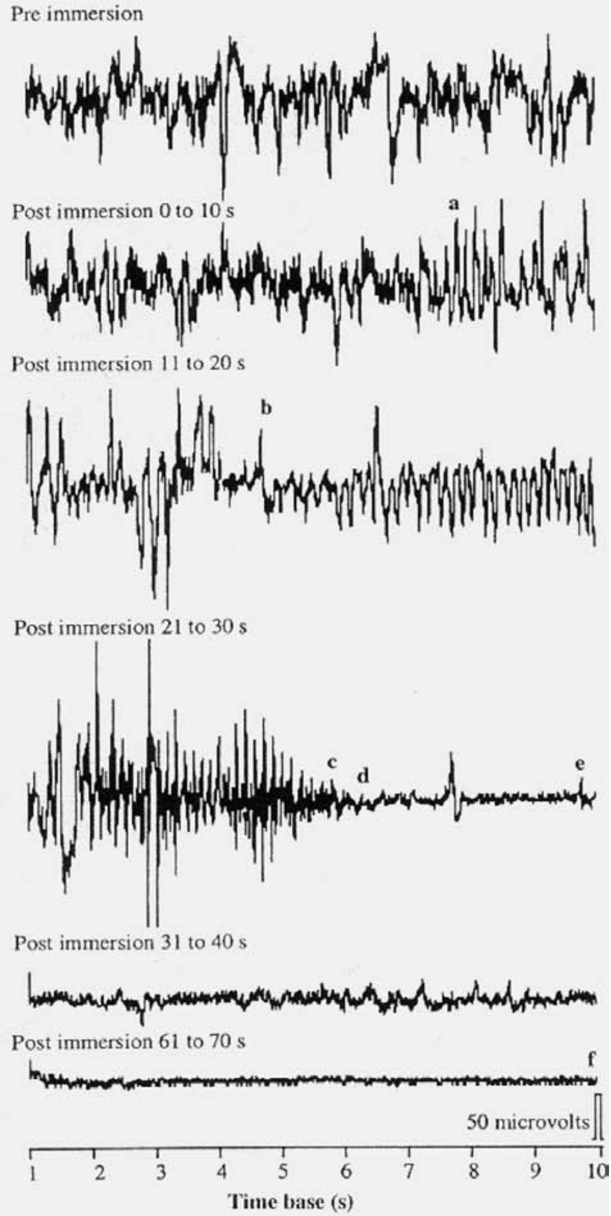

Figure 5.4. *Changes in the Spontaneous Electroencephalogram (EEG) of a Broiler during Exposure to Argon with Less Than 2% Oxygen (a = Onset of HALF Activity; b = Onset of Convulsions; c = End of Convulsions; d = Onset of EEG Suppression; e = Loss of SEPs; f = Onset of Isoelectric EEG). From Raj et al. (1998). With Permission.*

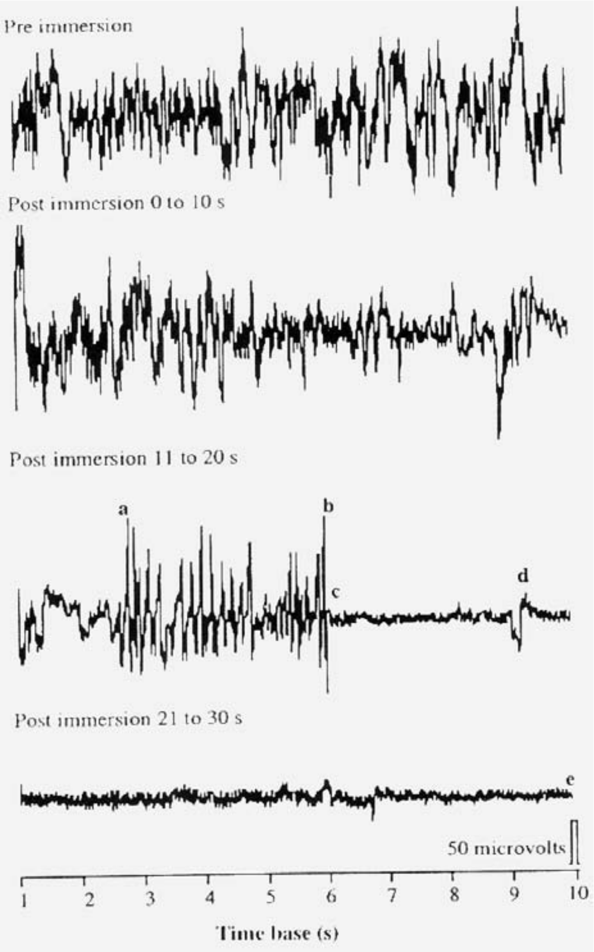

Figure 5.5. *Changes in the Spontaneous Electroencephalogram (EEG) of a Broiler during Exposure to a Mixture of 30% Carbon Dioxide and 60% Argon in Air (a = Onset of Convulsions; b = End of Convulsions; c = Onset of EEG Suppression; d = Loss of SEPs; e = Onset of Isoelectric EEG). From Raj et al. (1998). With Permission.*

was seen after 77, 83 and 93 seconds; in the other two gas mixtures studied, all of the birds died after 2 minutes. The 14 broilers that survived the 2 minute exposure to the third gas mixture showed two types of electrical activity. In eight out of the 14 broilers, the EEG remained suppressed during the 2 minute exposure to this gas mixture. In the other six broilers, frequent bursts of unipolar, low-frequency, high-amplitude spikes started occurring at random in the suppressed EEG (Figure 5.6). In general, the amplitude of the spikes

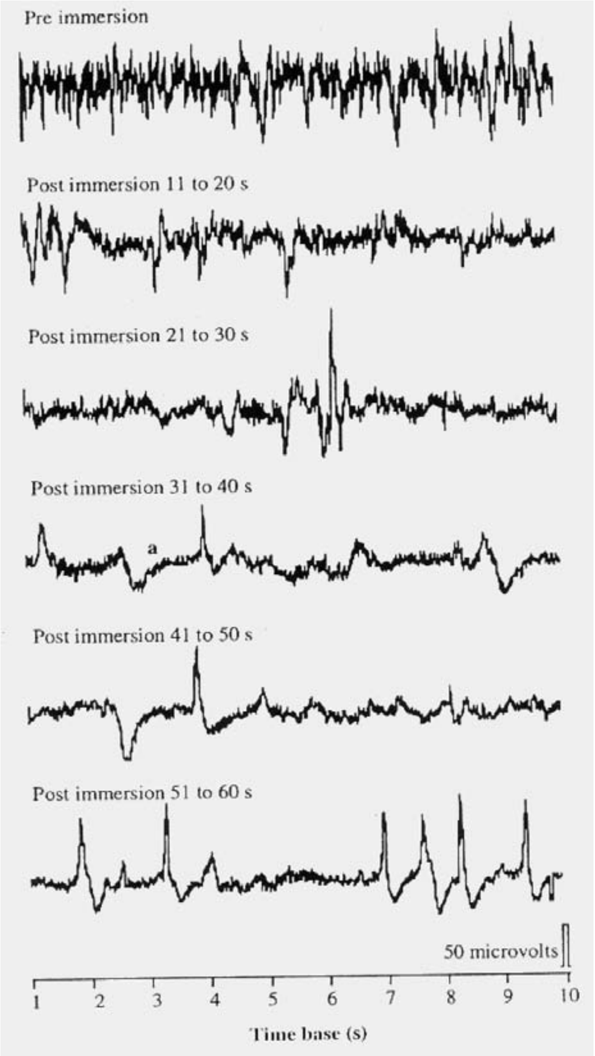

Figure 5.6. *Changes in the Spontaneous Electroencephalogram (EEG) of a Broiler during Exposure to a Mixture of 30% Oxygen, 40% Carbon Dioxide and 30% Nitrogen (a = Onset of Suppressed EEG with Random Spike Activity). From Raj et al. (1998). With Permission.*

gradually increased during the initial stages of their development. Analysis of variance showed that the time to onset of EEG suppression was similar in the Ar and CO_2 + Ar mixtures (17 +/− 1.9 and 19 +/− 1.9, respectively), and they were significantly shorter than the one reported for the $CO_2 + O_2 + N_2$ mixture (40 +/− 2.3 seconds).

Based on the time to onset of EEG suppression, exposure of broilers to the first two gas mixtures resulted in a quicker loss of consciousness than during exposure to a mixture of 40% CO_2, 30% O_2 and 30% N_2. The latter mixture has been suggested as an alternative stunning of broilers, followed by killing with a high concentration of CO_2. (Note: one such system is currently used in Europe.)

The time to induce anesthesia, with the three gas mixtures, was determined from the time observed to lose stomatal sensory-evoked potentials (SEP) in the brain. The mean time to lose SEP in chicken during exposure to Ar and the CO_2 + Ar mixtures were 29 and 19 seconds, respectively. For turkeys, times of 44 and 22 seconds, respectively, were recorded. The results indicate that the CO_2 + Ar mixture is more rapid than Ar alone in achieving a loss in brain function in both chickens and turkeys. However, the turkey brain appeared to be relatively more tolerant of anoxia than the chicken brain. Raj et al. (1998) have indicated that the use of CO_2 for killing chickens does not seem to have a welfare advantage over using 90% Ar in air or 30% CO_2 + 60% Ar in air. For turkeys, times to lose SEP during exposure to 50, 65 or 85% CO_2 in air were reported to be 20, 15 and 21 seconds, respectively. These times were not significantly different from the time measured when a mixture of Ar and CO_2 was used. In commercial trials, it has also been shown that turkeys stunned and killed with Ar or Ar + CO_2 mixtures showed less hemorrhaging in breast muscle and less downgrading over turkeys stunned with 50 Hz sinusoidal AC current.

NECK CUTTING AND BLEEDING

After stunning the birds, the blood vessels in the neck are cut. In North America, the blood vessels (both carotid arteries and jugular veins; see Figure 4.4) are usually cut by a deep ventral cut within 8 to 12 seconds of electrical stunning. This is accomplished using an automatic neck cutter with follow-up by backup personnel. Ensuring rapid blood drainage causes anoxia and often prevents birds from regaining consciousness during the subsequent 80–90 second bleed time. In Europe, neck cutting is usually performed dorsal laterally or on one side only. Because the rate of blood loss is slower, bleed times are usually extended to 120–180 seconds. This type of cut often leaves some blood supply to the brain, giving birds the opportunity to regain consciousness if the cut or bleeding is incomplete. This potential for regaining consciousness has been a major reason (from an animal welfare standpoint) that current levels of 120–150 mA per bird have been suggested in Europe to ensure an instantaneous and irreversible stun. Contrasting with Europe, electrical currents used in North America have traditionally been in the range of 25–45 mA per bird (Bilgili, 1999). Concerns over a deep bilateral neck cut in

Europe, which can often sever the trachea and might cause the head to come off in the picker, have, therefore, prevented European processors from using this technique in the past.

The time between stunning and neck cutting should be closely monitored to ensure adequate bleeding (Table 4.1). Usually, it is recommended that neck cutting be done within 1 minute of electrical stunning. It is inevitable that the time between the end of gas stunning/killing and neck cutting would be longer than is practiced under electrical stunning. Research has shown that the efficiency of bleeding in broiler chickens is not impaired when neck cutting is done immediately after gas stunning/killing. A long delay between the stunning and bleeding operations could increase the prevalence of downgrading associated with poor bleeding. In contrast, delayed neck cutting (after gas killing) of turkeys does not impede blood loss. The difference between chickens and turkeys may be attributable to a difference in carcass cooling rate, but other factors may also be involved (Raj and Johnson, 1997). The usual blood loss represents about 4–5% of the total body weight. However, the initial rate of bleeding has been shown to be slower in birds that were killed rather than stunned. Considering the minimum bleed-out time of 90 seconds for broilers and 120 seconds for turkeys in the United States, as prescribed in the legislation, the industry should be able to achieve a satisfactory bleed-out through a bilateral cut (Gregory and Wilkins, 1989b).

Another concern is that birds killed by inducing cardiac arrest during electrical or gas stunning might not bleed-out adequately because their wings might hang too low, resulting in stagnation of blood in their wing veins. Such situations could exacerbate the presence of engorged wing veins and, in association with the massaging of the plucking machine, it could cause hemorrhages in the wings. In fact, stunning currents that induce ventricular fibrillation in a high proportion of broilers are associated with a high incidence of red wing tips and hemorrhaging in the shoulder and wing areas.

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CHAPTER 6

Inspection, Grading, Cut Up and Composition

INTRODUCTION

POULTRY, like other meat-producing animals, are commonly inspected and graded prior to reaching the marketplace. Poultry inspection is mandatory in most countries and is used to assure that diseased animals do not transfer foodborne pathogens, toxins and/or antibiotics to humans. The spread of diseases from animals to humans is a major concern (e.g., avian flu or mad-cow disease which has cost the meat industry a great deal of money and aggravation). Inspection is commonly carried out by a designated government agency, so there is little room, if any, for deviation or compromising public interest. The process usually includes ante- and postmortem inspections. In areas where live poultry is sold directly to the consumer, individual bird inspection is not common, but, if information on a disease outbreak surfaces, government personnel will increase monitoring and inspection.

This chapter deals with the regulatory aspects of poultry inspection. Later, the grading of poultry, which is usually not mandatory (i.e., done on a voluntary basis in most countries), will be discussed. Although grading is not mandatory in most places, it is commonly done to facilitate trading.

Fresh poultry meat can be marketed as a whole eviscerated bird or as cut up pieces. There are various ways to portion the meat, and the cutting of different poultry species will be discussed in the chapter as it relates to retail, food service and industry use. Classification of the different kinds of poultry (e.g., chicken, turkey, duck, geese, guinea fowl and pigeon) is also provided. Over the years, precise portioning specifications have been developed in different parts of the world in order to increase uniformity and facilitate marketing. Examples of cut-up specifications for common poultry such as chicken, as well as ostrich and rhea, are described. Automated equipment specifically designed for poultry portioning is also presented. In the last section, the nutritional composition of various poultry cuts is provided.

INSPECTION

Inspection is commonly performed by trained government personnel responsible for ensuring that only wholesome poultry and poultry products, fit for human consumption, reach the marketplace. The reason this process is under governmental control is to ensure that no marketing pressures are exerted on inspection personnel. This is an important point in any public health matter where an independent body should decide, approve and later enforce the regulations. Personnel includes licensed inspectors, who may be veterinarians, or other individuals specifically trained to carry out the process.

Poultry inspection is usually divided into ante- and postmortem inspections. The inspection process is designed to prevent diseased birds from entering the marketplace and to minimize the chances of passing diseases to humans. In addition, the inspector ensures that the processed product is handled, packaged and labeled in accordance with each country's Inspection Act.

Birds that have passed inspection receive a stamp/legend (Figure 6.1) that signifies that they have passed an examination, by a qualified inspector, and are wholesome and fit for human consumption. Examples of the poultry postmortem regulations employed in the United States are provided below to illustrate the requirements and procedures (USDA, 1999a).

Carcass Disposition

First, the inspector must make a decision about the wholesomeness of each carcass inspected. If the carcass is wholesome, it is allowed to continue down the line.

If the carcass is wholesome except for a localized disease condition, it is allowed to continue unrestricted after removal of the affected areas. The dis-

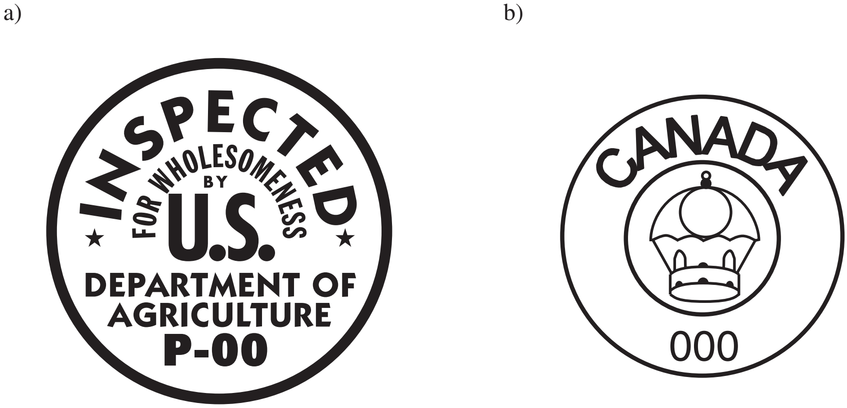

Figure 6.1. *Inspection Shields: (a) U.S. Inspected, See Plant Number at Bottom; (b) Canadian Shield.*

eased portion that was removed is handled as any other condemned material. If the carcass is considered unwholesome, the entire carcass is condemned.

The final consideration for carcass disposition involves questionable carcasses that require further examination. Borderline or questionable carcasses are placed on the hangback or retain rack pending further review.

Dispositions are made on carcasses based on the stage of disease development and the resolution of the disease or processes at the time of slaughter. If a disease process exists in the live animal, the pathogenesis of the disease stops at the time of slaughter, but the lesions of the disease will remain. The inspector's responsibility is to evaluate and interpret the pathological lesions present after the animal is slaughtered and prepared for postmortem inspection.

The criteria for condemnation in each category on FSIS Form 6000-16 (Lot Tally Sheet) are as follows:

(*1*) *Tuberculosis*. Avian tuberculosis (TB) is caused by the bacterium *Mycobacterium avium* and usually is a chronic, slowly developing disease. It has largely been eradicated in domestic poultry in the United States, but is still found occasionally in mature birds.

Birds with TB develop a wasting condition characterized by loss of weight and diarrhea. At postmortem examination, their carcasses are typically emaciated. Gray to yellow, firm nodules (tubercles) are often scattered along the intestines and may be found in various organs, especially in the liver and spleen. Lungs generally have no gross lesions, although, in advanced cases, any organ or tissue can be involved. Avian tuberculosis can infect humans but is not considered to be a serious threat to people with healthy immune systems. One definitive lesion is all that is required to condemn a poultry carcass for tuberculosis.

(*2*) *Leukosis*. This condemn category includes several neoplastic diseases caused by various viruses. All of them produce tumors in domestic poultry and present similar gross lesions. The age and species of bird affected by leukotic tumors suggests that viral agent that is involved. However, only a presumptive diagnosis can be made based on this information, because there is considerable overlap. The most common manifestations of the leukosis complex are as follows: (1) Marek's disease, which is an important disease found only in chickens less than six months of age; (2) lymphoid leukosis, which is most common in semi-mature and mature chickens; (3) reticuloendotheliosis, which occasionally produces liver and spleen tumors in turkeys and, rarely, runting disease in chickens; and (4) lymphoproliferative disease, which affects turkeys, producing a greatly enlarged spleen as well as tumors in other organs. There is no evidence that viruses of the leukosis complex are pathogenic for humans. One definitive lesion is all that is needed to justify condemnation of the carcass. Definitive means a lesion that can be defended grossly as a lesion of leukosis.

(*3*) *Septicemia/toxemia*. Septicemia is a disease state caused by pathogenic (disease-producing) microorganisms in the blood that have produced systemic change within the bird. Systemic change affects the body as a whole rather than localized portions of it. In septicemia, the normal functions of the bird's organ systems are disrupted. The cells of the body deteriorate. This deterioration may be very rapid when highly virulent microorganisms are the cause, or it may be more gradual if less virulent ones are involved. In some cases, the changes produced by the septicemia will overwhelm the bird and result in its death. In other cases, the bird's immune system will overcome the causative organism before irreversible damage occurs, and it will recover. Septicemia is manifested by a group of clinical signs, not all of which will be present in a single carcass. Therefore, judgement plays an important part in correct dispositions for this condemn category. Septicemic carcasses frequently have petechial (pinpoint) hemorrhages on the heart, liver, kidneys, muscles and serous membranes. Blood-tinged exudates are often present in the body cavity. The liver and spleen are often swollen and hyperemic (contain an excess of blood), because they remove most of the bacteria from the circulating blood. Kidneys may appear swollen and congested. The skin of septicemic birds may be hyperemic. Depending upon the cause and duration of septicemia, carcasses at the time of slaughter may be hyperemic, cyanotic, anemic, dehydrated and edematous or exhibit some combination of these signs. No single carcass will show all of these signs. Septicemia/toxemia is commonly referred to as sep/tox. If a carcass shows systemic change, it is condemned. This category is a catchall for those carcasses that have septicemia, toxemia or a combination of septicemia-toxemia.

(*4*) *Synovitis*. Synovitis may be caused by a number of organisms, most often members of the genus *Mycoplasma*. Injury and nutritional deficiencies can also lead to synovitis. The result is acute or chronic inflammation of the membranes lining one or more joints and tendon sheaths. Joints are often noticeably swollen and may contain exudate of variable amounts and consistency. The liver, kidneys and spleen may be swollen, and the liver is sometimes stained green from bile stasis. Lesions vary depending upon whether or not the condition has been confined to the joints without affecting the overall health of the bird or has overwhelmed the bird's defense mechanisms and caused systemic changes. A carcass that has synovitis and also shows signs of sep/tox or systemic change is condemned. In other words, a carcass with synovitis is not condemned unless it also shows systemic change.

(*5*) *Tumors*. Several types of tumors besides those of the leukosis complex affect domestic poultry. Some of the more common ones include squamous cell carcinomas, adenocarcinomas, leiomyomas and fibromas.

Squamous cell carcinomas are skin tumors found in young chickens. Adenocarcinomas generally are located on abdominal organs and are common in older birds. Leiomyomas are most often identified in the oviduct of fowl and fibromas may develop in any connective tissue and are also more common in older birds. Numerous other types of tumors occur in domestic poultry but at a low frequency. There is no evidence that any of these types of tumors are a health threat to humans. Condemn a carcass for tumors if there is "gross evidence" of metastasis present. The general rule is as follows: one tumor—trim and pass; two or more tumors—condemn if there is evidence of metastasis. Exclude leukosis from the tumor category. Leukosis is in a separate category.

(*6*) *Bruises*. If bruises are the reason for systemic change in a carcass, then the carcass is condemned and recorded under the bruises category.

(*7*) *Cadaver*. Poultry that die from causes other than slaughter are condemned under the cadaver category. Generally, the bird is not dead at the time of entering the scald vat and, upon submersion into the scald water, drowns.

(*8*) *Contamination*. Carcasses that are contaminated to the extent that valid inspection cannot be made are condemned. An example would be a carcass contaminated with bile or feces to the extent that the inspector cannot determine whether the carcass is wholesome. Carcasses that fall into open sewers or evisceration troughs are condemned under the contamination category.

(*9*) *Overscald*. Carcasses that are cooked are condemned. Many times, these carcasses will also be machine-mutilated by picking machines.

(*10*) *Airsacculitis*. Numerous microorganisms can produce airsacculitis, inflammation of air sacs. Often, more than one infectious agent is identified in an outbreak. Members of the genus *Mycoplasma* are frequently involved. Birds are more susceptible to infections of the air sacs when they are under stress. Vaccination, other disease, poor nutrition, insanitary conditions and poor ventilation may all be contributing factors. The lesions of airsacculitis can be acute or chronic. Their appearance can range from slight clouding of air sac membranes and small amounts of watery exudate to thickened, opaque membranes and large amounts of thick, white-to-cream colored and/or cheesy exudates. The exudates can be confined to the air sacs and their diverticula, or they may be found in other areas if the air sac membranes are ruptured. Pneumonia, pericarditis and perihepatitis might be present. In some cases, all portions of the respiratory tract (nasal passages, sinuses, trachea, bronchi, lungs, and air sacs and their diverticula) are affected. In other cases, little involvement beyond the air sacs is evident. One organism that can cause airsacculitis in birds, *Chlamydia psittaci,* can cause disease in humans. Outbreaks of this disease are sporadic and generally occur in turkeys rather than chickens. The turkey industry watches for any evidence of chlamydiosis so infected flocks generally are identified and treated before slaughter. However, inspectors must stay alert for any poultry that show signs suspicious for this disease. Carcasses are condemned if airsacculitis occurs in conjunction with systemic change. An airsacculitis condemnation is also justified by the presence of extensive airsacculitis. In the latter instance, the amount of exudate present prevents a valid evaluation of the wholesomeness of the carcass. If the exudate cannot be effectively removed, the carcass is also condemned.

(*11*) *Other*. There are several other subgroups:
- Inflammatory process: if the condition is generalized, the carcass is condemned.
- Plant rejects: if the plant elects to reject a carcass for inspection, it is condemned.
- Carcasses condemned because there are no viscera available to inspect: disposition of no-viscera carcasses is determined by the veterinarian in charge and is based upon flock incidence of disease.
- Xanthomatosis: if the condition is generalized, the carcass is condemned.
- Parasites: if the infestation is generalized, the carcass is condemned.

Only condemnation of carcass parts is required for some localized conditions. If there is an unwholesome portion or part that can be effectively removed, the remainder of the carcass would be considered wholesome. Some organs or parts that may be condemned because of localized conditions without condemning the whole carcass are as follows:

- *Livers:* livers that have fatty degeneration are condemned. Livers that have extensive petechiae or hemorrhaging must be condemned. A liver that is inflamed, has an abscess, has a necrotic area, or is affected with necrosis, is condemned. Cirrhotic livers, livers that have a single nonleukotic tumor or livers with cysts are also condemned. Discolorations in the liver due to a biliary system disorder or postmortem changes result in the liver being condemned. Livers are condemned if there has been contamination from intestinal content or noxious materials.
- *Kidneys:* when there is renal or splenic pathology or hepatic lesions that cause liver condemnation, the kidneys must be removed. Pathological conditions requiring condemnation of all viscera also require the kidneys to be removed. Anytime there is airsacculitis, the kidneys must be removed when the carcass or its posterior portion is salvaged.
- *Fractures:* a fracture with no associated hemorrhage need not be trimmed and can be passed. But, a fracture with a hemorrhage of the affected part must be trimmed. A compound fracture, one in which the skin is broken, requires trimming, whether there is hemorrhage present or not.

- *Luxations:* a luxation is a simple disjointment with no skin broken and no hemorrhage. The condition need not be trimmed. Hemorrhage extending into the musculature requires trimming or slitting/washing out. Simple redness of skin does not require any action.

To maintain a good production rate, one properly trained plant employee should be designated for each inspector as the inspector's helper in doing the following:

- Remove condemned birds or parts from the line and place them in the designated U.S. condemn containers.
- Remove retained carcasses from the line and place them in the appropriate area of the retain rack, designated for veterinary review.
- Remove from the line carcasses designated for approved off-line salvage and place them in the appropriate area of the retain rack.
- Record condemned carcasses in the appropriate blocks of the inspector's worksheet (FSIS Form 6000-16) as directed by the inspector.
- Mark carcasses, at the inspector's direction, for trim or salvage.
- Trim abnormalities.
- Assist as much as possible to allow the inspector to devote full attention to postmortem inspection. The inspector and the helper must work as a team. The inspector may use various methods to give directions to the helper. In some cases, hand signals are given, but in other situations, directions are given by voice.

Line Speeds

FSIS does not require line speed adjustments due to the number of feathers on carcasses presented for postmortem inspection. Plant management is responsible for line speed adjustments related to ready-to-cook poultry.

FSIS uses the following considerations to decide if a line speed adjustment is needed:

- poultry class and the size of the birds in the class
- presentation errors, such as viscera on the wrong side or not presented in a consistent manner
- disease incidence
- plant personnel's ability to accomplish eviscerating procedures sanitarily with a minimum of contamination
- physical limitations of inspectors
- plant facilities

Maximum line speeds established by FSIS will be permitted on the eviscerating line in the poultry plant when optimum conditions exist. When less than optimum conditions are present, a line speed adjustment is required. The inspector in charge is responsible for directing plant management to reduce the line speed to the degree necessary to permit adequate inspection and insure a smooth flow of product.

When the inspector in charge is satisfied that the situation that made the line speed reduction necessary has been corrected, he or she will permit resumption of the previous line speed.

Plant Management Responsibilities

Plant management is required to provide these facilities at the postmortem inspection station:

Space: the amount of space required for the inspector and helper varies depending upon the inspection method.

Lighting: lighting requirements also vary between inspection methods. The minimum lighting requirements are as follows:

- Traditional inspection, 50 foot-candles
- Streamlined inspection system (SIS), 200 foot-candles
- New line speed inspection system (NELS), 200 foot-candles
- New turkey inspection system (NTIS), 200 foot-candles

Other factors as important as the quantity of foot-candles are the quality and direction of light. Light should not cause color changes on the inspected carcasses and should be shadow-free.

Hand-washing facilities: water for hand washing with a minimum temperature of 65°F must be available to the inspectors working at the postmortem inspection station.

Condemned containers: generally, there are two types of condemned containers at the postmortem inspection station. One type is for parts, and one is for the whole carcass. These containers must be leak-proof and properly marked, indicating "U.S. Condemned Product" in legible letters that are at least two inches high.

Holder for inspection form: the plant uses this device to hold the lot tally sheet or FSIS Form 6000-16 (USDA, 1999a) so that it is conveniently located for the plant helper to record dispositions as instructed by the USDA postmortem inspector.

Hangback racks: the primary purpose of the hangback rack is to retain questionable carcasses for veterinary review and disposition. The racks can also be used for carcasses designated as salvage, improper presentation, etc.

Other facility requirements: an adjustable platform is required at each inspection station. Reinspection stations must be provided at both the pre-chill and post-chill locations.

Plant management should also make every effort to minimize the occurrence of contamination of the opening of the carcass in preparation for evisceration. The modified J-cut is the opening cut most processors use, although the bar-cut is also used.

Sanitation and consistency are important for a properly drawn carcass. Traditionally, viscera must be completely withdrawn, left suspended by natural attachments and arranged consistently to the left or right side.

With increasing frequency, modern poultry slaughter plants are using automatic equipment on the eviscerating line. Often, the equipment is complex and requires careful and regular adjustment for consistently proper function. It is the responsibility of plant management to maintain the machinery so that it works properly.

The plant may use one of several methods available for suspending carcasses in the shackles. The plant may use a two-point or three-point suspension depending on the plant's facilities and local preference. Carcasses must be presented at the postmortem inspection station shackled in a consistent manner.

The shackles must be identified on lines that have more than one inspector. They may be color coded or mechanically separated (as in the case of "selectmatic" devices that "kick out" carcasses automatically). The latter helps reduce fatigue by taking "the search factor" out of postmortem inspection.

GRADING

Grading is commonly done on a voluntary basis after birds have passed the mandatory inspection. The grade standards, developed by each country or trading community, are applied to a specific kind and class of poultry. However, some general criteria are considered in assessing most poultry. Factors such as overall conformation, presence of pinfeathers, discoloration and missing parts are fairly universal criteria applied to all kinds of poultry.

The grading can be done by government-licenced graders or a private agency working under government regulations (i.e., various countries have privatized the grading system in order to reduce costs). In any case, developing national standards that are acceptable to all participants (e.g., producers, processors, consumers) is more easily done and monitored by a central body agreeable to all local and potential international buyers. In most places, the grading service is based on a fee for service. Examples of grading stamps are shown in Figure 6.2.

The general standards used for grading ready-to-cook poultry in the United States are provided below. The description in the text refers to Grade A chicken. Tables 6.1a, b and c provide the actual limits for Grades A, B and C, respectively (USDA, 1998). The major criteria for Grade A are as follows:

(*1*) *Conformation:* the carcass or part is free of deformities that detract from its appearance or that affect the normal distribution of flesh.

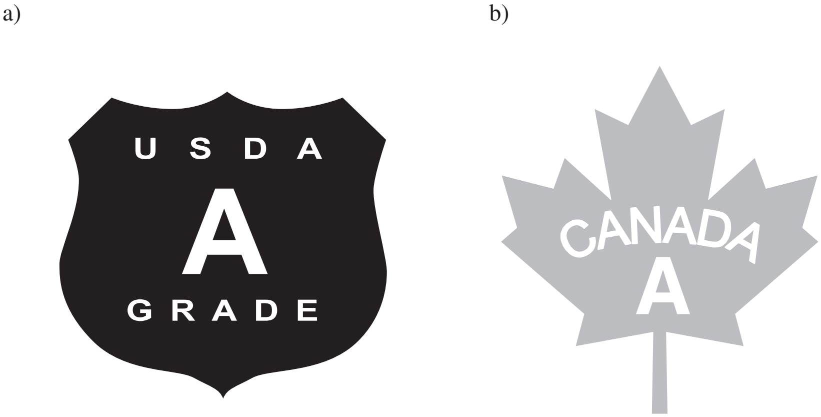

Figure 6.2. *Grade Stamps: (a) U.S. Grade A; (b) Canada.*

Slight deformities, such as slightly curved or dented breastbones and slightly curved backs, may be present.

(*2*) *Fleshing:* the carcass has a well-developed covering of flesh, considering the kind, class and part. The breast is moderately long and deep, and has sufficient flesh to give it a rounded appearance, with the flesh carrying well up to the crest of the breastbone along its entire length (see Figure 6.3). The leg is well fleshed and moderately thick and wide at the knee and hip joint area, and has a well-rounded, plump appearance with the flesh carrying well down toward the hock and upward to the hip joint area. The drumstick is well fleshed and moderately thick and wide at the knee joint and has a well-rounded, plump appearance with the flesh carrying well down toward the hock. The thigh is well to moderately fleshed. The wing is well to moderately fleshed.

(*3*) *Fat covering:* the carcass or part, considering the kind, class and part, has a well-developed layer of fat in the skin. The fat is well distributed so that there is a noticeable amount of fat in the skin in the areas between the heavy feather tracts.

(*4*) *Defeathering:* the carcass or part shall have a clean appearance, especially on the breast and legs, and shall be free of protruding feathers. A carcass or part shall be considered free from protruding feathers when it complies with the tolerances specified in Table 6.1a.

(*5*) *Discoloration:* the requirements contained in this section are applicable to discolorations of the skin and flesh of poultry and the flesh of skinless poultry. The carcass, parts derived from the carcass or large carcass parts may have slight discolorations, provided the discolorations do not detract from the appearance of the product.

The carcass may have lightly shaded areas of discoloration, provided the aggregate area of all discolorations does not exceed an area

Table 6.1a. Summary of Specifications for Standards of A-Quality for Individual Carcasses and Parts Used in the United States (USDA, 1998)

		A Quality					
Conformation:		Normal					
Breastbone		Slight curve or dent					
Back		Slight curve					
Legs and Wings		Normal					
Fleshing:		Well fleshed, considering kind and class					
Fat Covering:		Well-developed layer—especially between heavy feather tracts					
Defeathering: Free of protruding feathers and hairs		**Turkeys**		**Ducks and Geese**[a]		**All Other Poultry**	
		(feathers less than 3/4 in.)		(feathers less than 1/2 in.)		(feathers less than 1/2 in.)	
		Carcass	**Parts**	**Carcass**	**Parts**	**Carcass**	**Parts**
		4	2	8	4	4	2
Exposed Flesh:[b] Weight Range		**Carcass**		**Large Carcass Parts**[c] (halves, front and rear halves)		**Other Parts**[c]	
Minimum	Maximum	Breast and Legs	Elsewhere	Breast and Legs	Elsewhere		
None	2 lbs.	1/4 in.	1 in.	1/4 in.	1/2 in.	1/4 in.	
Over 2 lbs.	6 lbs.	1/4 in.	1 1/2 in.	1/4 in.	3/4 in.	1/4 in.	

(continued)

Table 6.1a. (continued)

Over 6 lbs.	16 lbs.	1/2 in.	2 in.	1/2 in.	1 in.	1/2 in.
Over 16 lbs.	None	1/2 in.	3 in.	1/2 in.	1 1/2in.	1/2 in.
Discolorations: **Carcass**		**Lightly Shaded**			**Moderately Shaded[d]**	
		Breast and Legs	Elsewhere		Hock of Leg	Elsewhere
None	2 lbs.	3/4 in.	1 1/4 in.		1/4 in.	5/8 in.
Over 2 lbs.	6 lbs.	1 in.	2 in.		1/2 in.	1 in.
Over 6 lbs.	16 lbs.	1 1/2 iin.	2 1/2 in.		3/4 in.	1 1/4 in.
Over 16 lbs.	None	2 in.	3 in.		1 in.	1 1/2 in.
Discolorations: **Large Carcass Parts** (halves, front and rear halves)		**Lightly Shaded**			**Moderately Shaded[d]**	
		Breast and Legs	Elsewhere		Hock of Leg	Elsewhere
None	2 lbs.	1/2 in.	1 in.		1/4 in.	1/2in.
Over 2 lbs.	6 lbs.	3/4 in.	1 1/2 in.		3/8 in.	3/4 in.
Over 6 lbs.	16 lbs.	1 in.	2 in.		1/2 in.	1 in.
Over 16 lbs.	None	1 1/4 in.	2 1/2 in.		5/8 in.	1 1/4 in.
Discolorations: **Other Parts**		**Lightly Shaded**			**Moderately Shaded[d]**	

Table 6.1a. (continued)

None	2 lbs.	1/2 in.	1/4 in.
Over 2 lbs.	6 lbs.	3/4 in.	3/8 in.
Over 6 lbs.	16 lbs.	1 in.	1/2 in.
Over 16 lbs.	None	1 1/4 in.	5/8 in.
Disjointed and Broken Bones:		Carcass—one disjointed and no broken bones. Parts—thighs with back portion, legs or leg quarters may have femurs disjointed from the hip joint. Other parts—none.	
Missing Parts:		Wing tips and tail. In ducks and geese, the parts of the wing beyond the second joint may be removed if removed at the joint, and both wings are so treated. The tail may be removed at the base.	
Freezing Defects:		Slight darkening on back and drumstick. Overall bright appearance. Occasional pockmarks due to drying. Occasional small areas of clear, pinkish- or reddish-colored ice.	

[a] Hair or down is permitted on the carcass or part, provided the hair or down is less than 3/16 inch in length and is scattered so that the carcass or part has a clean appearance, especially on the breast and legs.

[b] Maximum aggregate area of all exposed flesh. In addition, the carcass or part may have cuts or tears that do not expand or significantly expose flesh, provided the aggregate length of all such cuts and tears does not exceed a length tolerance equal to the permitted dimensions listed above.

[c] For all parts, trimming of skin along the edge is allowed, provided at least 75% of the normal skin cover associated with the part remains attached, and the remaining skin uniformly covers the outer surface and does not detract from the appearance of the part.

[d] Moderately shaded discolorations and discolorations due to flesh bruising are free of clots and limited to areas other than the breast and legs except for the area adjacent to the hock.

Table 6.1b. Summary of Specifications for Standards of B-Quality for Individual Carcasses and Parts Used in the United States (USDA, 1998)

<table>
<tr><th colspan="2"></th><th colspan="6">B Quality</th></tr>
<tr><td colspan="2">Conformation:</td><td colspan="6">Moderate deformities</td></tr>
<tr><td colspan="2"><i>Breastbone</i></td><td colspan="6">Moderately dented, curved or crooked</td></tr>
<tr><td colspan="2"><i>Back</i></td><td colspan="6">Moderately crooked</td></tr>
<tr><td colspan="2"><i>Legs and Wings</i></td><td colspan="6">Moderately misshaped</td></tr>
<tr><td colspan="2">Fleshing:</td><td colspan="6">Moderately fleshed, considering kind and class</td></tr>
<tr><td colspan="2">Fat Covering:</td><td colspan="6">Sufficient fat layer—especially on breast and legs</td></tr>
<tr><td colspan="2" rowspan="3">Defeathering:
A few scattered protruding feathers and hairs</td><td colspan="2">Turkeys
(feathers less than 3/4 in.)</td><td colspan="2">Ducks and Geese[a]
(feathers less than 1/2 in.)</td><td colspan="2">All Other Poultry
(feathers less than 1/2 in.)</td></tr>
<tr><td>Carcass</td><td>Parts</td><td>Carcass</td><td>Parts</td><td>Carcass</td><td>Parts</td></tr>
<tr><td>6</td><td>3</td><td>10</td><td>5</td><td>6</td><td>3</td></tr>
<tr><td colspan="2">Exposed Flesh:
Weight Range</td><td colspan="3" rowspan="2">Carcass</td><td colspan="3" rowspan="2">Parts</td></tr>
<tr><td>Minimum</td><td>Maximum</td></tr>
<tr><td>None</td><td>2 lbs.</td><td colspan="3" rowspan="2">No part on the carcass (wings, legs, entire back or entire breast) has more than one-third of the flesh exposed</td><td colspan="3" rowspan="2">No more than one-third of the flesh normally covered by skin exposed</td></tr>
<tr><td>Over 2 lbs.</td><td>6 lbs.</td></tr>
</table>

Table 6.1b. (continued)

Over 6 lbs.	16 lbs.		
Over 16 lbs.	None		
Discolorations:[b] **Carcass**		**Carcass** Lightly or Moderately Shaded Discolorations	
		Breast and Legs	Elsewhere
None	2 lbs.	1 1/4 in.	2 1/4 in.
Over 2 lbs.	6 lbs.	2 in.	3 in.
Over 6 lbs.	16 lbs.	2 1/2 in.	4 in.
Over 16 lbs.	None	3 in.	5 in.
Discolorations:[b] **Large Carcass Parts** (halves, front and rear halves)		**Large Carcass Parts** Lightly or Moderately Shaded Discolorations	
		Breast and Legs	Elsewhere
None	2 lbs.	1 in.	1 1/4 in.
Over 2 lbs.	6 lbs.	1 1/2 in.	1 3/4 in.
Over 6 lbs.	16 lbs.	2 in.	2 1/2 in.
Over 16 lbs.	None	2 1/2 in.	3 in.

(continued)

Table 6.1b. (continued)

Discolorations:[b] **Other Parts**		**Other Parts** Lightly or Moderately Shaded Discolorations	
		Breasts, Legs and Parts	
None	2 lbs.	3/4 in.	
Over 2 lbs.	6 lbs.	1 in.	
Over 6 lbs.	16 lbs.	1 1/2 in.	
Over 16 lbs.	None	1 3/4 in.	
Disjointed and Broken Bones:		Carcass—two disjointed and no broken bones, or one disjointed and one nonprotruding broken bone. Parts—may be disjointed, no broken bones; wing beyond second joint may be removed at a joint.	
Missing Parts:		Wing tips, second wing joint and tail.	
Trimming:		**Carcass**	**Parts**
		Slight trimming of the carcass is permitted provided the meat yield of any part on the carcass is not appreciably affected. The back may be trimmed in an area not wider than the base of the tail to the area halfway between the base of the tail and the hip joints.	A moderate amount of meat may be trimmed around the edge of a part to remove defects.
Freezing Defects:		May lack brightness. Few pockmarks due to drying. Moderate areas showing a layer of clear, pinkish- or reddish-colored ice.	

[a] Hair or down is permitted on the carcass or part, provided the hair or down is less than 3/16 inch in length and is scattered so that the carcass or part has a clean appearance, especially on the breast and legs.

[b] Discolorations due to flesh bruising shall be free of clots and may not exceed one-half the total aggregate area of permitted discoloration.

Table 6.1c. Summary of Specifications for Standards of C-Quality for Individual Carcasses and Parts Used in the United States (USDA, 1998)

		C Quality					
Conformation:		Abnormal					
Breastbone		Seriously curved or crooked					
Back		Seriously crooked					
Legs and Wings		Misshapen					
Fleshing:		Poorly fleshed					
Fat Covering:		Lacking in fat covering over all parts of carcass					
Defeathering:		**Turkeys**		**Ducks and Geese**[a]		**All Other Poultry**	
Scattering of protruding feathers and hairs		(feathers less than 3/4 in.)		(feathers less than 1/2 in.)		(feathers less than 1/2 in)	
		Carcass	**Parts**	**Carcass**	**Parts**	**Carcass**	**Parts**
		8	4	12	6	8	4
Exposed Flesh: Weight Range		**Carcass**			**Parts**		
Minimum	Maximum						
None	2 lbs.	No limit					
Over 2 lbs.	6 lbs.						
Over 6 lbs.	16 lbs.						
Over 16 lbs.	None						

(continued)

Table 6.1c. (continued)

Discolorations:		**Carcass**	
Carcass		Breast and Legs	Elsewhere
None	2 lbs.	No limit on size, number of areas or intensity of discolorations and flesh bruises if such areas do not render any part of the carcass unfit for food.	
Over 2 lbs.	6 lbs.		
Over 6 lbs.	16 lbs.		
Over 16 lbs.	None		
Discolorations: **Parts** (includes large carcass parts)		**Parts** Breasts, Legs and Parts	
None	2 lbs.	No limit on size, number of areas or intensity of discolorations and flesh bruises if such areas do not render any part unfit for food.	
Over 2 lbs.	6 lbs.		
Over 6 lbs.	16 lbs.		
Over 16 lbs.	None		
Disjointed and Broken Bones:		No limit	

Table 6.1c. (continued)

	Carcass	**Parts**
Missing Parts:	Wing tips, wings and tails. Backs shall include all meat and skin from pelvic bones, except that the meat contained in the ilium (oyster) may be removed. The vertebral ribs and scapula with meat and skin and the backbone located anterior (forward) if ilia bones may also be removed (front half of back).	
Trimming:	Trimming of the breast and legs is permitted but not to the extent that the normal meat yield is materially affected. The back may be trimmed in an area not wider than the base of the tail and extending from the tail to the area between the hip joints.	
Freezing Defects:	Numerous pockmarks and large dried areas.	

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[a] Hair or down is permitted on the carcass or part, provided the hair or down is less than 3/16 inch in length and is scattered so that the carcass or part has a clean appearance, especially on the breast and legs.

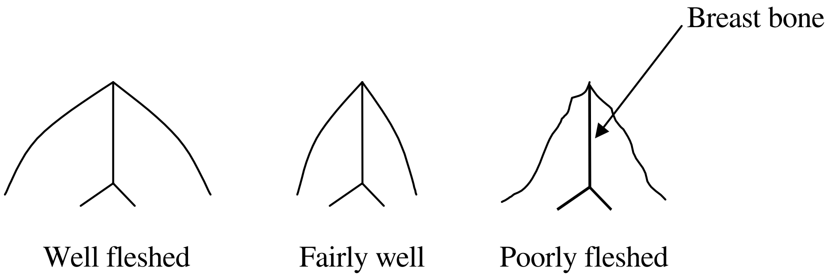

Figure 6.3. *A Cross Section of Poultry Breast Area Showing Variation in the Amount of Flesh Covering the Breastbone. Drawing on the Left Shows an Example of Grade A.*

equivalent to the area of a circle of the diameter specified in Table 6.1a. Evidence of incomplete bleeding, such as more than an occasional slightly reddened feather follicle, is not permitted.

The carcass may have moderately shaded areas of discoloration and discolorations due to flesh bruising, provided the following:

- They are not on the breast or legs, except for the area adjacent to the hock joint.
- They are free of clots.
- They may not exceed an aggregate area equivalent to the area of a circle of the diameter specified in Table 6.1a.

Parts, other than large carcass parts, may have lightly shaded areas of discoloration, provided the aggregate area of all discolorations does not exceed an area equivalent to the area of a circle of the diameter specified in Table 6.1a. Evidence of incomplete bleeding, such as more than an occasional slightly reddened feather follicle, is not permitted. Parts, other than large carcass parts, may have moderately shaded areas of discoloration and discolorations due to flesh bruising, provided the following:

- They are not on the breast or legs, except for the area adjacent to the hock joint.
- They are free of clots.
- They may not exceed an aggregate area equivalent to the area of a circle of the diameter specified in Table 6.1a.

Large carcass parts, specifically halves, front halves or rear halves, may have lightly shaded areas of discoloration, provided the aggregate area of all discolorations does not exceed an area equivalent to the area of a circle of the diameter specified in Table 6.1a. Large carcass parts, specifically halves, front halves, or rear halves, may have moderately shaded areas of discoloration and discolorations due to flesh bruising, provided the following:

- They are not on the breast or legs, except for the area adjacent to the hock joint.

- They are free of clots.
- They may not exceed an aggregate area equivalent to the area of a circle of the diameter specified in Table 6.1a.

(*6*) *Disjointed/broken bones and missing parts:* parts are free of broken bones. Parts are free of disjointed bones except that thighs with back portions, legs or leg quarters may have the femur disjointed from the hip joint. The carcass is free of broken bones and has not more than one disjointed bone.

The wing tips may be removed at the joint, and in the case of ducks and geese, the parts of the wing beyond the second joint may be removed, if removed at the joint and both wings are so treated. The tail may be removed at the base.

Cartilage separated from the breastbone is not considered a disjointed or broken bone.

(*7*) *Exposed flesh:* the requirements contained in this section are applicable to exposed flesh resulting from cuts, tears and missing skin.

Large carcass parts, specifically halves, front halves or rear halves, may have exposed flesh due to cuts, tears and missing skin, provided the aggregate area of all exposed flesh does not exceed an area equivalent to the area of a circle of the diameter specified in Table 6.1a.

The carcass may have exposed flesh due to cuts, tears and missing skin, provided the aggregate area of all exposed flesh does not exceed an area equivalent to that of a circle of the diameter specified in Table 6.1a.

For all parts, trimming of the skin along the edge is allowed, provided that at least 75% of the normal skin cover associated with the part remains attached, and further provided that the remaining skin uniformly covers the outer surface in a manner that does not detract from the appearance of the part.

Other parts may have exposed flesh due to cuts, tears and missing skin, provided the aggregate area of all exposed flesh does not exceed an area equivalent to that of a circle of the diameter specified in Table 6.1a.

In addition, the carcass or part may have cuts or tears that do not expand or significantly expose flesh, provided the aggregate length of all such cuts and tears does not exceed a length tolerance using the dimensions listed in Table 6.1a.

(*8*) *Freezing defects:* with respect to consumer packaged poultry, parts or specified poultry food products, the carcass, part or specified poultry food product is practically free from defects that result from handling or occur during freezing or storage. The following defects are permitted if they, alone or in combination, detract only very slightly from the appearance of the carcass, part or specified poultry food product:

- slight darkening over the back and drumsticks, provided the frozen bird or part has a generally bright appearance

- occasional pockmarks due to drying of the inner layer of skin (derma); however, none may exceed the area of a circle 1/8 inch in diameter for poultry weighing 6 pounds or less and 1/4 inch in diameter for poultry weighing over 6 pounds.
- occasional small areas of clear, pinkish or reddish colored ice
- occasional small areas of dehydration, white to light gray in color, on the flesh of skinless carcasses, parts or specified poultry food products not to exceed the permitted aggregate area for discolorations as provided in Table 6.1. Note: A-quality backs shall meet all applicable provisions of this section pertaining to parts and shall include the meat contained on the ilium (oyster), pelvic meat and skin and vertebral ribs and scapula with meat and skin.

An internal, in-plant system for deboned meat and/or parts can sometimes be used and may include the following:

- presence of bruises and/or blood clots
- presence of bones and cartilage
- other factors

It should be mentioned that in recent years, a grading system based on meat quality attributes, such as water-holding capacity and texture, has been discussed for use by the industry. Such a system is of interest to further processors who are looking for meat that will hold added moisture and not fall apart during cooking regardless of skin tears or missing parts (Barbut, 1998).

CLASSIFICATION

Chicken Classifications

The following are the various classes of poultry used in the United States (USDA, 1998):

a. *Rock Cornish game hen or Cornish game hen.* A Rock Cornish game hen or Cornish game hen is a young immature chicken (usually five to six weeks of age), weighing not more than 2 pounds ready-to-cook weight, that was bred from a Cornish chicken or the progeny of a Cornish chicken crossed with another breed of chicken.

b. *Rock Cornish fryer, roaster or hen*. A Rock Cornish fryer, roaster or hen is the progeny of a cross between a purebred Cornish and a purebred Rock chicken, without regard to the weight of the carcass involved; however, the term “fryer,” “roaster” or “hen” shall apply only if the carcasses are from birds with ages and characteristics that qualify them for such designation under paragraphs (c) and (d) of this section.

c. *Broiler or fryer*. A broiler or fryer is a young chicken (usually under 13 weeks of age), of either sex, that is tender-meated with soft, pliable, smooth-textured skin and flexible breastbone cartilage.
d. *Roaster or roasting chicken*. A bird of this class is a young chicken (usually three to five months of age), of either sex, that is tender-meated with soft, pliable, smooth-textured skin and breastbone cartilage that may be somewhat less flexible than that of a broiler or fryer.
e. *Capon*. A capon is a surgically unsexed male chicken (usually under eight months of age) that is tender-meated with soft, pliable, smooth-textured skin.
f. *Hen, fowl or baking or stewing chicken*. A bird of this class is a mature female chicken (usually more than 10 months of age) with meat less tender than that of a roaster or roasting chicken and a nonflexible breastbone tip.
g. *Cock or rooster*. A cock or rooster is a mature male chicken with coarse skin, toughened and darkened meat and hardened breastbone tip.

Turkey Classifications

a. *Fryer-roaster turkey*. A fryer-roaster turkey is a young immature turkey (usually under 16 weeks of age), of either sex, that is tender-meated with soft, pliable, smooth-textured skin and flexible breastbone cartilage.
b. *Young turkey*. A young turkey is a turkey (usually under eight months of age) that is tender-meated with soft, pliable smooth-textured skin and breastbone cartilage that is somewhat less flexible than that of a fryer-roaster turkey. Sex designation is optional.
c. *Yearling turkey*. A yearling turkey is a fully matured turkey (usually under 15 months of age) that is reasonably tender-meated with reasonably smooth-textured skin. Sex designation is optional.
d. *Mature turkey or old turkey (hen or tom)*. A mature or old turkey is an old turkey of either sex (usually in excess of 15 months of age) with coarse skin and toughened flesh.
e. For labeling purposes, the designation of sex within the class name is optional, and the two classes of young turkeys may be grouped and designated as “young turkeys.”

Author’s comment: turkeys are usually ordered by weight (most commonly 8–24 lb) and by weight ranges, such as young toms, 16–18, 18–20, 20–22, 22–24 and >24 lb; for young hens, the weight starts from 8–10 lb.

Duck Classifications

a. *Broiler duckling or fryer duckling*. A broiler duckling or a fryer duckling is a young duck (usually under eight weeks of age), of either sex, that is tender-meated and has a soft bill and a soft windpipe.

b. *Roaster duckling*. A roaster duckling is a young duck (usually under 16 weeks of age), of either sex, that is tender-meated and has a bill that is not completely hardened and a windpipe that is easily dented.

c. *Mature duck or old duck*. A mature duck or an old duck is a duck (usually over six months of age), of either sex, with toughened flesh, hardened bill and hardened windpipe.

Geese Classifications

a. *Young goose*. A young goose may be of either sex, is tender-meated and has a windpipe that is easily dented.

b. *Mature goose or old goose*. A mature goose or old goose may be of either sex and has toughened flesh and a hardened windpipe.

Guinea Fowl Classifications

a. *Young guinea*. A young guinea may be of either sex, is tender-meated and has flexible breastbone cartilage.

b. *Mature guinea or old guinea*. A mature guinea or an old guinea may be of either sex and has toughened flesh and a hardened breastbone.

Pigeon Classifications

a. *Squab*. A squab is a young, immature pigeon of either sex that is extra tender-meated.

b. *Pigeon*. A pigeon is a mature pigeon of either sex, with coarse skin and toughened flesh.

CUT UP AND YIELD

There are different ways to cut up a poultry carcass. A broiler chicken will be used as an example for the cutting operation; however, this system can apply to most poultry. Depending on market demand, poultry can be sold as a whole, ready-to-cook bird, split into two halves, separated into different parts (wings, legs) and sold with/without skin and bones (e.g., boneless breast). A list of commercial cuts is provided in Table 6.2. The list is part of a system used by the North American Meat Processors Association (NAMP, 1999). The orga-

Table 6.2. A Numbering System Used to Label Each Individual Species and Cut Listed in a Buyers Guide Developed by the North American Meat Processors Association (NAMP, 1999). With Permission.

Key to Identify Birds: 1st and 2nd Digits				Key to Identify Cuts: 3rd and 4th Digits			
P10	Broiler/fryer	P70	Quail	0	Whole carcass	34	Thigh with back portion
P11	Roaster chicken	P71	Pharaoh quail	1	Carcass with giblets	35	Drumstick
P12	Capon	P72	Pheasant	2	Carcass without giblets (WOG[a])	36	Whole wing
P13	Fowl (not commonly available)	P73	Baby pheasant	3	Front half	37	Wing drumette
P14	Poussin	P74	Partridge	4	Lower portion	38	Wing flat (mid joint)
P15	Rock Cornish game hen	P75	Chukar (partridge)	5	Eight (8)-piece cut (WOG)	39	Wing tip (tip or flipper)
P20	Young turkey			6	Nine (9)-piece cut (WOG)	40	Wing portion
P21	Tom			7	Ten (10)-piece cut (WOG)	41	Back
P22	Hen			8	Halves (half carcass)	42	Neck
P23	Mature (not commonly available)			9	Quarter	43	Giblets
P24	Breeder tom (not commonly available)			10	Breast quarter	44	Gizzard
P25	Breeder hen (not commonly available)			11	Breast quarter without wing	45	Liver
P26	Wild turkey			12	Whole breast with ribs	46	Foie gras

(continued)

Table 6.2. (continued)

Key to Identify Birds: 1st and 2nd Digits		Key to Identify Cuts: 3rd and 4th Digits			
P30	Duckling	13	Whole breast without ribs	47	Feet
P31	Roaster duckling	14	Breast half with ribs	48	Paws
P32	Mature duck (not commonly available)	15	Breast half without ribs	49	Bones
P40	Young goose	16	Airline breast (airline style)	50	Tongue
P41	Mature goose (not commonly available)	30	Leg quarter	51	Testicles (Fries)
P50	Guinea fowl	31	Leg	52	Heart
P60	Squab	32	Semi-boneless leg	53–99	Reserved for future use
P61	Pigeon (not commonly available)	33	Thigh		

[a] WOG—term given to broilers sold without giblets and neck.

nization has designed a numbering system for easy communication and standardization of poultry cuts sold to retailers and the food service industry. The system consists of one letter followed by four numbers. The letter designates the type of meat-producing animal; P is assigned to poultry. This is followed by two digits used to identify the type of bird. The following third and fourth digits are used to identify the cut. A number such as P1012 identifies a portion from poultry (P), taken from a broiler (10) and cut as a whole breast (12). The table shows different kinds of poultry and the commercial cuts available.

The descriptions and definitions of meat cuts and their proper names (nomenclature) are obviously very important for the seller and buyer. The following are definitions used by the Canadian Food Inspection Agency (CFIA, 1999) provided as an example:

Poultry: refers to a meat derived from dressed carcasses of birds as defined by the Meat Inspection Act and Regulations. (Note: the name of the bird from which the meat is derived is required to appear in the product description in lieu of the word poultry.)

Dressed poultry carcass (whole poultry): refers to a poultry carcass from which the feathers, head, the feet at the tarsal joints and uropygial gland have been removed and which has been eviscerated.

Poultry half (half poultry): refers to one of the two approximately equal portions of a dressed poultry carcass obtained by cutting through the backbones (thoracic vertebrae; see Figure 6.4), pelvic bones (pelvis) and keel bone (sternum) along the median line. (Note: the poultry half excludes the neck.)

Front quarter: refers to the front (anterior) portion of a poultry half obtained by cutting immediately behind (posterior to) and parallel to the rib cage [posterior to the seventh (7th) thoracic vertebra, seventh (7th) rib and sternum].

Hindquarter: refers to the hind (posterior) portion of a poultry half that is separated from the front quarter. (Note: the term leg, back attached, may also be used to identify this cut.)

Wing: refers to that portion of the whole poultry obtained by cutting through the shoulder joint (articulation between the clavicle, coracoid and humerus). It includes the wing drumette and the winglet and may include the wing tip (see Figure 6.4; wing).

Wing drumette: refers to the proximal portion of the wing that is separated from the whole poultry by cutting through the shoulder joint as described, and from the winglet by cutting through the elbow joint (articulation between the humerus and radius/ulna). (Note: the wing drumette shall not be referred to as drumstick.)

Winglet: refers to that distal portion of the wing obtained by cutting through the elbow joint (articulation between the humerus and radius/ulna). Part of the wing tip may be removed.

Leg: means that portion of the whole poultry obtained by cutting at the natural seam through the hip joint (articulation between the femur and the pelvis;

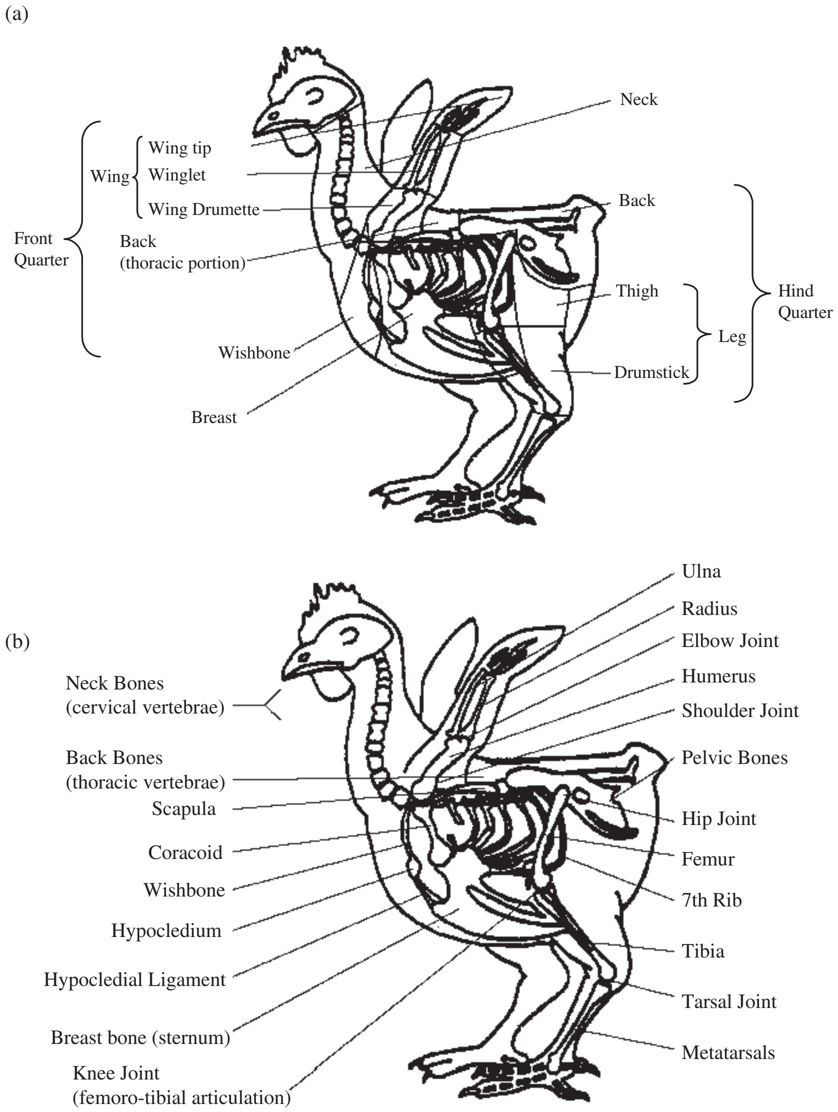

Figure 6.4. *Diagram of Meat Cuts (a), and a General Skeletal Diagram (b). From CFIA (1999).*

see Figure 6.4). It includes the thigh and drumstick jointed or disjointed and may include pelvic meat. It excludes pelvic bones, back skin, abdominal skin and excess fat.

Thigh: means that proximal portion of the leg that is separated from the whole poultry by cutting at the natural seam through the hip joint as described, and from the drumstick by a straight cut through the knee joint (femoro-tibial articulation). It may include pelvic meat but shall exclude pelvic bones, back skin, abdominal skin and excess fat.

Drumstick: means that distal portion of the leg that is separated from the thigh by a straight cut through the knee joint as described in the thigh section.

Breast: means that portion of the whole poultry that is separated from the wing by cutting through the shoulder joint, from the neck by cutting approximately through the twelfth (12th) neck bone (cervical vertebra; see Figure 6.4), from the back by cutting through the ribs at the junction of the vertebral ribs and back and from the hindquarter by cutting immediately behind (posterior to) the rib cage (seventh rib and sternum). The breast includes the "Y"-shaped ends of the ribs and excludes the neck skin. [Note: the breast may be portioned in two approximately equal parts (half breast) as described or in three parts by first removing the wishbone portion then by cutting the breastbone (sternum) along the median line. For exact weight-making purposes, these parts may be substituted for lighter or heavier pieces, and the package may contain two or more of such parts without affecting the appropriateness of the product description as breast.]

Half Breast: means one of the two approximately equal portions of a breast obtained by cutting through the breastbone (sternum) along the median line.

Wishbone: refers to the front (anterior) portion of the breast obtained by cutting through the hypocledial ligament located between the tip of the wishbone (hypocledium) and the front point of the breastbone (carinal apex of the sternum), then between the wishbone (clavicle) and coracoid up to a point where the wishbone (clavicle) joins the shoulder. The neck skin is excluded.

Trimmed breast: means that portion of the breast obtained by cutting along the junction of the vertebral and sternal ribs. The sternal ribs may be removed, and the neck skin shall be excluded. [Note: the trimmed breast may be portioned in two approximately equal parts (half-trimmed breast) as described or in three parts by first removing the wishbone portion as described, then by cutting the breastbone (sternum) along the median line. For exact weight-making purposes, these parts may be substituted for lighter or heavier pieces, and the package may contain two or more such parts without affecting the appropriateness of the product description as trimmed breast.]

Half-trimmed breast: means one of the two approximately equal portions of a trimmed breast obtained by cutting through the breastbone (sternum) along the median line.

Breast fillet: is the round, elongated fusiform muscle (supracoracoid muscle or deep pectoral) found on each side of the keel bone (sternum).

Whole back: means the portion of the whole poultry that is separated from the breast as described in the breast section. It includes the neck, thoracic vertebrae, pelvic bones and tail. It may include parts of the vertebral ribs.

Back: means that portion of the whole back that is separated from the neck by cutting in the vicinity of the shoulder joint (approximately through the twelfth cervical vertebra). It includes the thoracic vertebrae, pelvic bones and tail, skin and adhering meat. The vertebral ribs and/or scapula may be removed.

Stripped back: means the back from which the meat adhering to the pelvic bones has been removed.

Neck: means that front (anterior) portion of the whole back or carcass obtained by cutting near the shoulder joint (approximately through the twelfth cervical vertebra). It may include the skin.

Poultry giblets: means the liver, the heart or the gizzard or any combination thereof of the same species, obtained from a dressed poultry carcass.

Ground poultry: means fresh, boneless, skinless comminuted poultry meat that has a fat content identified by one of the following terms:

- regular, 30%
- medium, 23%
- lean, 17%
- extra lean, 10%

For a more detailed description of the major breast and thigh muscles, see Figure 6.5(a) and 6.5(b), respectively. Figure 6.5(a) shows the interior breast muscles as they appear once the upper layer of muscles has been removed. The skinless thigh portion [Figure 6.5(b)] shows the muscles as they appear to the consumer once the skin has been removed.

Equipment Used for Deboning

The significant increase in marketing deboned poultry parts (see Chapter 1) resulted in increased demand for equipment that can assist cutting and deboning operations. Today, different options are available to the processor. They range from the traditional hand deboning operation to highly automated equipment that can cut up and debone a whole bird.

The traditional hand deboning of poultry includes wing, breast and leg removal from the chilled and aged carcasses. Hand deboning can be done with the carcasses are placed on a cutting table or on a stationary/moving deboning cone. Figure 6.6 shows a moving cone system where each employee is assigned to one or two cuts. The carcasses are placed on the cone at the beginning of the line and slowly moved forward. The deboning usually starts by removing the wings (see previous discussion on cutting) then the breast meat with/without skin removal. This is done by cutting the anterior ends of the pectoral muscles and stripping the muscle from the bone. This usually leaves the small pectoral muscles attached to both sides of the sternum, from which they can be manually stripped. The small pectoral muscles can be sold sepa-

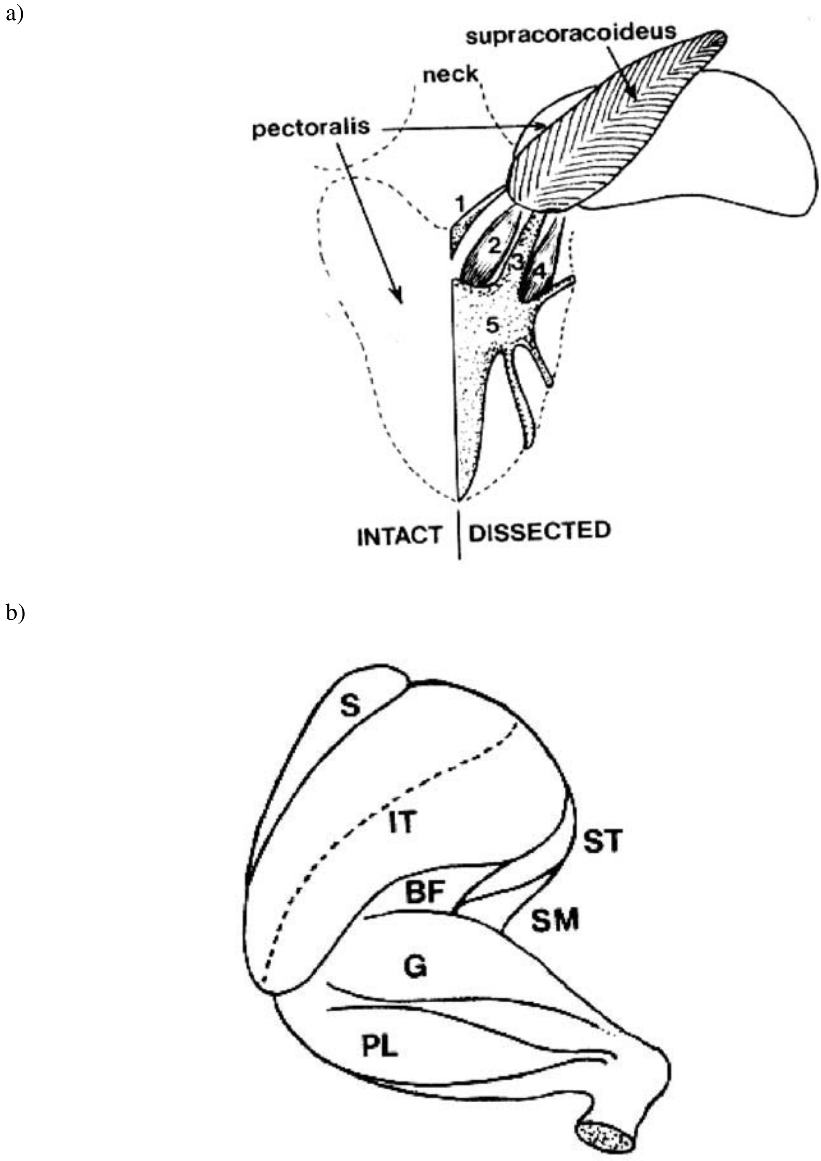

Figure 6.5. *The Major Poultry Muscles as Seen after Skin Removal and Dissection (a) The Breast: (1) Clavicle, (2) Minor Head of Supracoracoideus, (3) Coracoid, (4) Posterior Coracobrachialis, (5) Sternum. (b) The Leg Portion: Biceps Femoris (BF), Gastrocnemius (G), Iliotibialis (IT), Peroneus Longus (PL), Sartorius (S), Semimembranosus (SM), Semitendinosus (ST). From Swatland (1994). With Permission.*

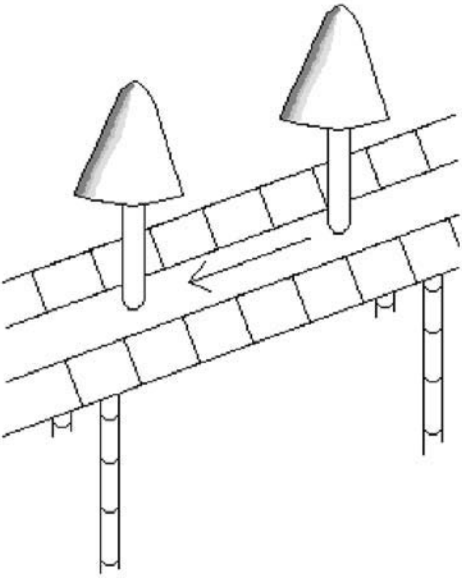

Figure 6.6. *A Cone System Used to Assist Manual Deboning.*

rately as chicken/turkey “tenderloins.” The thighs can then be removed by cutting the abdominal skin followed by cutting through the femur-pelvis joint. If a skinless product is desired, the skin would be taken off prior to removing the leg. The leg section can be separated into the drumstick and thigh by cutting through the femoro-tibial joint (see Figure 6.4). Boneless thigh meat can be obtained by removing the femur bone as well as the major ligaments.

Automated cutting equipment is gaining popularity with the increased demand for convenient boneless poultry meat. Another factor that is pushing the development of automated equipment is the imbalance in demand for light and dark meat. Overall, in places such as North America, there is a very strong demand for light meat (see Chapter 1), so processors are left with significant amounts of dark meat. Deboning of the dark meat and incorporating it in further processed products and marinated products or selling it as boneless meat are important in obtaining a better price for the product. The equipment used should provide high output and precise deboning (i.e., to minimize the occurrence of bone chips). The design of such equipment represents a significant challenge to the manufacturer because the equipment should also be capable of handling birds of different sizes and configurations. A few examples of equipment currently used for cutting up and deboning poultry are provided below.

- Leg quarter cutter—is used to cut the back half of poultry into leg quarters (Figure 6.7). A spring-loaded centric guidance assembly

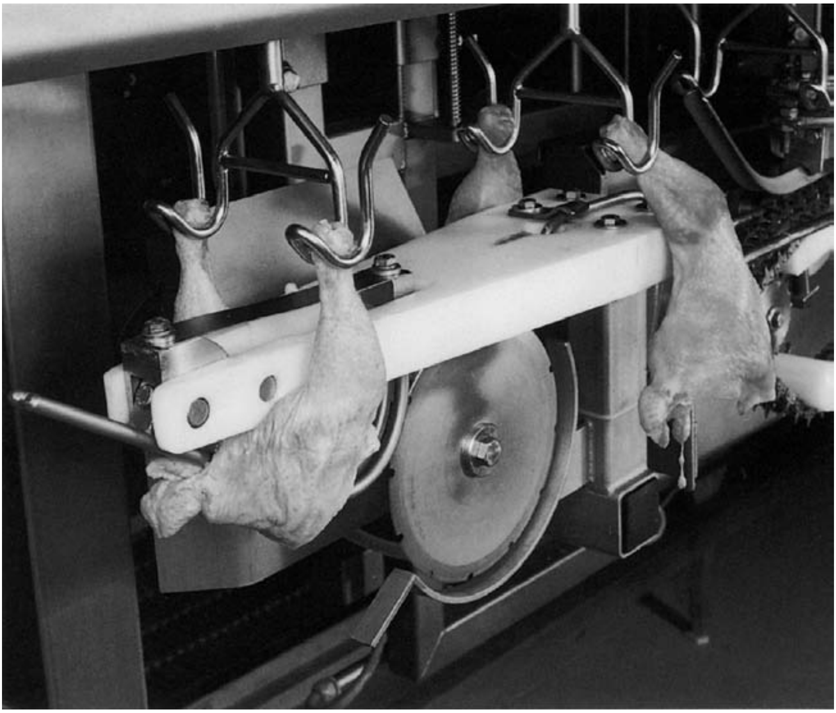

Figure 6.7. *An Automated Leg Quarter Cutter. Courtesy of Baader/Johnson, Kansas City, KS, U.S.A.*

stretches and centers the back half (i.e., after the front half has already been separated). A circular knife rotating in the opposite direction separates the back half into two quarters. Alternatively, the back can be cut out by using double knives. The machine can process a few thousand pieces an hour. Usually, this operation is part of a process used to split the carcass into various portions, as will be discussed later.

- Chicken halving machine—is used to obtain two front halves and two whole legs from a whole chicken carcass (Figure 6.8). The figure shows a double-spiral halving machine with built-in cutters. In order to make precise cuts at the hipbone joint, the machine forces the hip joint to stay in its natural position regardless of differences in carcass size. This is important in preventing bone fragmentation. Cutting at the different stations is also shown at the bottom of the figure. The machine is capable of processing 3,600 carcasses/hour.
- Whole turkey leg deboning operation—is used to automatically debone the meat and cut the sinew (Figure 6.9). The different cutting steps, in each station, are shown in the figure. The different operations mimic

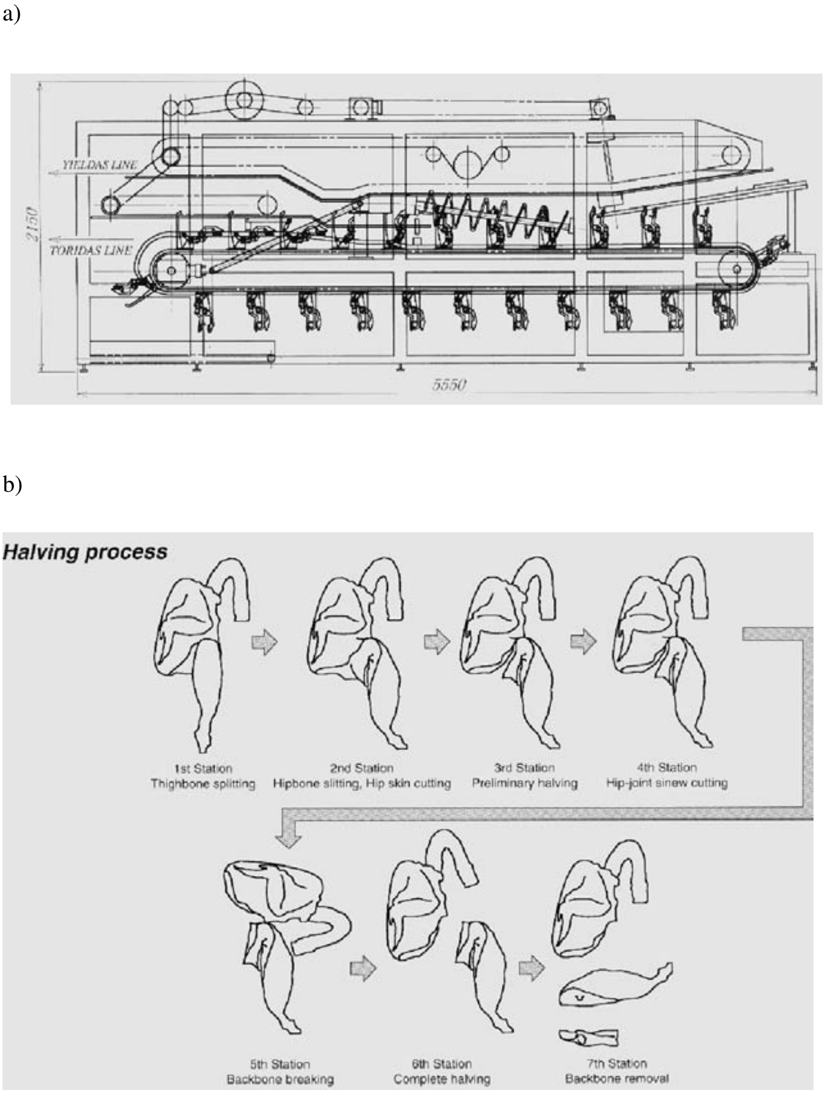

Figure 6.8. *An Automated Chicken Halving Machine (a) and the Cuts Obtained (b). Courtesy of Mycom Inc., Tokyo, Japan.*

the activities of a skilled manual worker, but according to the manufacturer, the machine can accomplish the task ten times faster. A major point in the design and operation of the equipment is to minimize/eliminate the inclusion of cartilage, pin bone and bone fragments in the final product. It should also be mentioned that companies

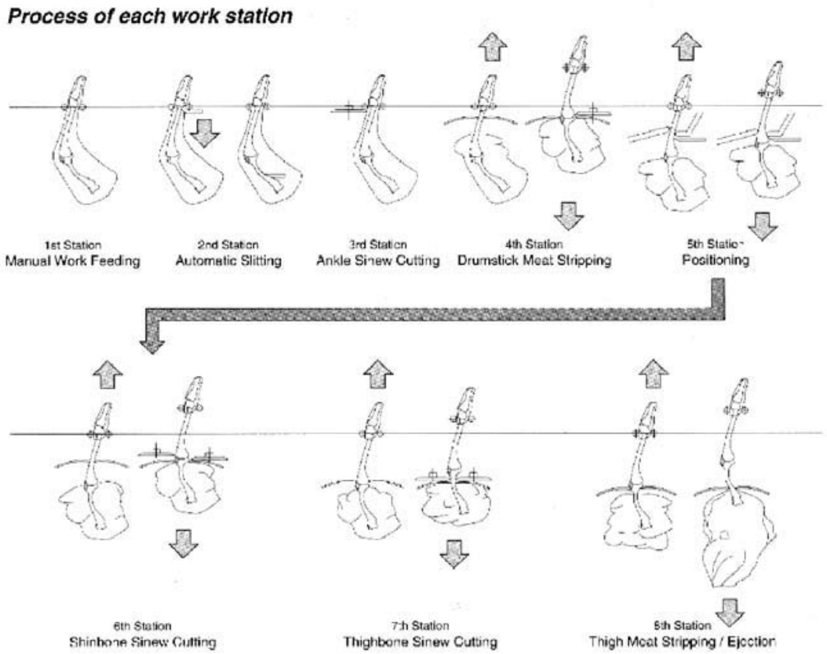

Figure 6.9. *A Whole Turkey Leg Deboning Operation. Courtesy of Mycom Inc., Tokyo, Japan.*

using the equipment have reported a reduction in the so-called "repetitive motion injuries" suffered by employees that do the job manually.

- Module system for leg deboning—uses back halves as raw material (Figure 6.10). Overall, the concept of having the process go through different modules (e.g., leg, thigh, breast deboning) is gaining popularity. Such a system allows flexibility in processing different birds in different ways. Birds can be sent to different cut-up modules depending on current market needs (e.g., more deboned breast fillets), differential prices, grade of incoming birds, etc. The module shown in the figure is elevated and can be easily monitored and inspected at all times. The whole module can be lowered for cleaning/repair in between shifts, so all the parts are easily accessible for cleaning or maintenance.
- Water jet portioning of deboned meat—is another concept currently gaining popularity within the meat industry. Figure 6.11 shows an example of a high-pressure water jet. The meat portion, moving on a conveyor belt, is first photographed from different angles so a three-dimensional image can be obtained. The image is used for calculating cutting lines to meet weight and shape requirements. The meat portion continues to move on the belt and is then cut by one or more water

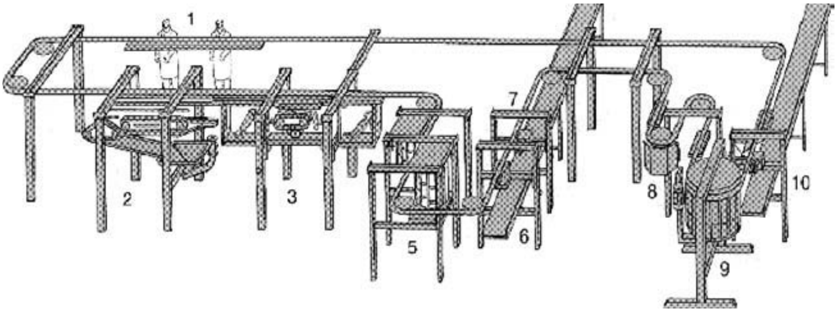

Figure 6.10. *An Example of a Compact Leg Deboning System Starting from Back Halves. Module Parts Include the Following: (1) Back Half Feeding, (2) Anatomic Leg Cutting Module, (3) Whole Leg Skinning Module, (4) Right-Hand Thigh Deboning Module, (5) Left-Hand Thigh Deboning Module, (6) Left-Hand Thigh Meat Harvesting Module, (7) Right-Hand Thigh Meat Harvesting Module, (8) Drumstick Cutting Module, (9) Drumstick Deboning Module and (10) Drumstick Meat Harvesting Module. Courtesy of Stork Inc., Boxmeer, The Netherlands.*

jets positioned above the product. The lower part of the figure shows an example of the breast meat portions that can be obtained (e.g., nuggets, fillets and "butterflies"). The machine is computer controlled, and information concerning meat and fat densities is used to calculate the appropriate volume needed to obtain a certain weight of each cut. Capital investment is high, but according to the manufacturer, cost recovery takes about one year. The equipment can handle about 80 "butterfly" cuts per minute.

Mechanically Deboned Meat

The residual meat remaining on the frames, necks and backs of hand-deboned or automated-cut poultry is usually harvested by the so-called mechanical deboning equipment, and the meat obtained is called mechanical deboned meat (MDM). The equipment can also be used for deboning whole spent hens or meat from parts that would not yield high-priced meat and justify the cost of hand deboning. The first mechanical deboner was developed in Japan in the early 1940s for fish meat. Salvaging the meat after hand filleting was of economical importance, and the resulting minced meat could be used for making other products. These were two important driving forces in developing the equipment, as was the case 15–20 years later for poultry. The increased demand for deboned poultry meat and the excess amount of frames left behind, as well as interest in products such as frankfurters (see recipe in Chapter 9), helped to develop the market for mechanically deboned poultry meat.

Currently, there are three basic types of deboners on the market (Field, 1988):

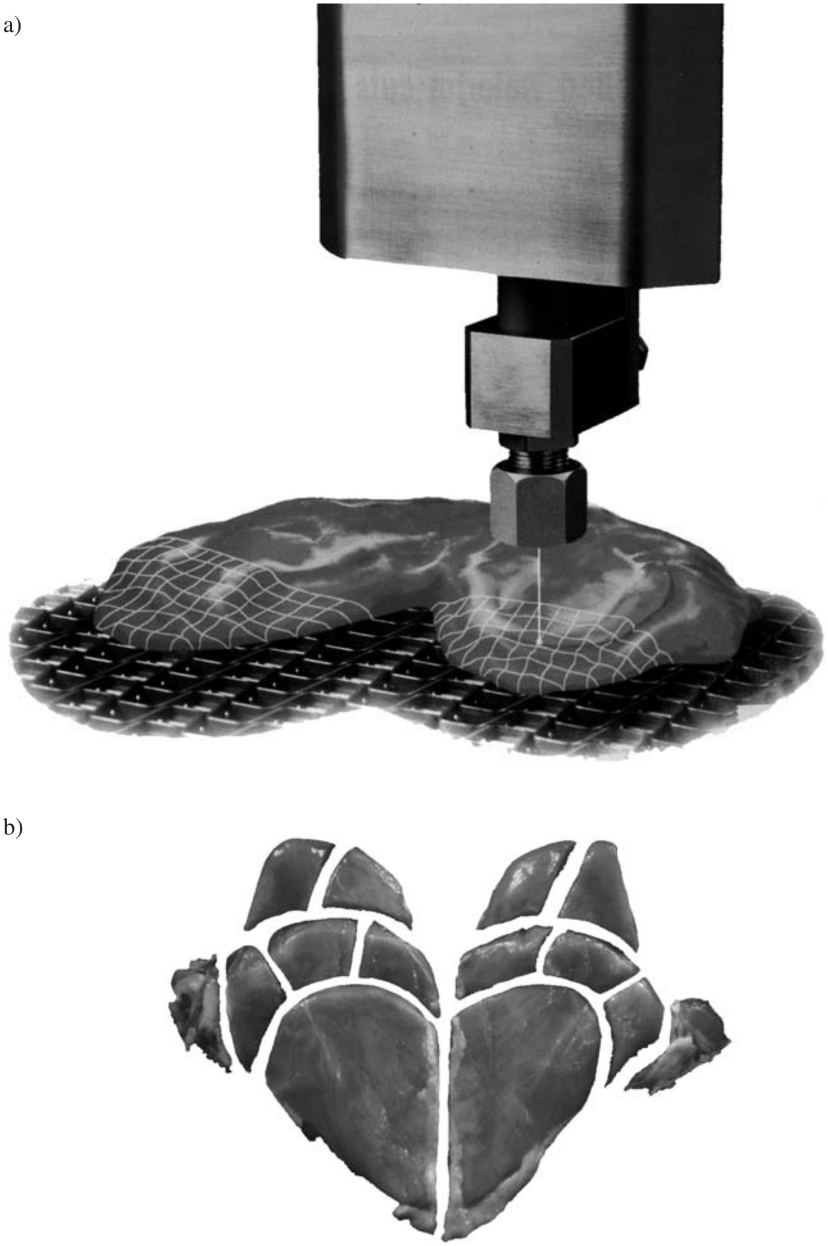

Figure 6.11. *A Water Jet Cutting System (a) and an Example of Poultry Breast Cuts (b). Courtesy of Stein DSI, Sandusky, OH, U.S.A.*

- The belt-drum system was initially developed for fish but was also used for poultry. In this system, the tissue is passed between a rubber belt and a micro-grooved steel drum. The meat is squeezed through the perforated steel drum while the harder bones and connective tissue remain on the outside. Pressure on the belts can be adjusted, and sometimes, pressure rollers are used to ensure an even distribution of the tissue on the belt.
- A rotating auger is used for fish, poultry and red meat. In this case, the bones and frames go through a bone cutter that reduces their size. The ground mixture is introduced into a screw-driven boning head. The material is pressed (with increasing pressure), and the meat is squeezed out through the perforated steel cylinder encasing the auger (Figure 6.12). The size of the holes can be adjusted and is usually around 0.5 mm. The bone and connective tissue particles that cannot pass through the perforated cylinder are pushed forward and exit at the end of the head.
- The hydraulically pressed batch system has been used for fish and poultry, but mainly for red meat. The bones are also pre-cut prior to being introduced into a batch-type chamber. Inside, the material is forced against a stationary, slotted surface by a high-pressure, hydraulic-powered ram piston. The high force squeezes the soft meat tissue through the cylinder openings (usually 1.3 × 1 mm).

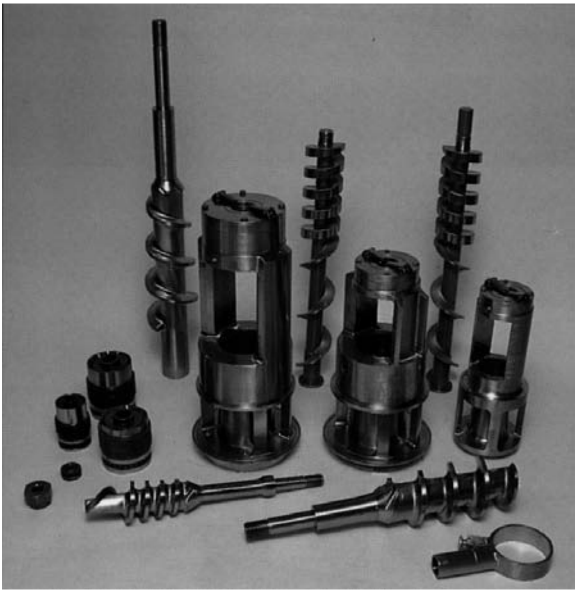

Figure 6.12. *Equipment Used for Mechanical Deboning. Courtesy of Weiler and Company Inc., Whitewater, WI, U.S.A.*

The texture of the mechanically deboned meat is that of a finely ground product that has a paste-like consistency in which the myofibrils are heavily fragmented. Under the microscope, breaks in the Z-line and distortion of the sarcomere (see Chapter 2 for sarcomere structure) can be seen as a result of the shearing force inside the deboner. The paste-like texture is suitable for finely chopped (also called emulsified) meat products such as bologna and frankfurters. The meat can also be used in a coarse-ground product where a fine comminuted matrix is used. A product such as smoked turkey sausage (recipe provided in Chapter 9) has a fine batter and coarse meat portions, where the coarse inserts are embedded within a homogeneous, finely chopped matrix.

The process of mechanical deboning makes the meat highly susceptible to lipid oxidation due to the extensive cellular disruption and release of enzymes. In addition, exposure of a large surface area to air, during the process, and the extraction of heme and lipids from bone marrow can also make the meat more susceptible to rancidity (Froning, 1981; Field, 1988). Ways to minimize oxidative rancidity include partial oxygen exclusion by vacuum packaging, the addition of vitamin E to the diet of the birds and/or the addition of natural/synthetic antioxidants to the further processed meat product. The rate of lipid oxidation is also influenced by the pressure exerted on the meat during the deboning process. Higher pressure will result in higher yield (Table 6.3), however, it will also increase the amount of iron in the sample as well as the proportion of some of the unsaturated fatty acids. The results reported in Table 6.3 refer to employing an auger-type deboner equipped with a 10 cm boning head, set at 1 mm spacing. High pressure of 150 lb/in^2 almost doubled the yield, but it also increased iron content by about 70%. Most of the increase in iron content has been reported to be hemoglobin (Froning, 1981). The heme content can vary considerably depending on the bone-to-meat ratio, deboner settings, skin content and the age of the bird. The high aeration rates during the process (i.e., exposure of large surface area to air) result in converting most of the myoglobin oxymyoglobin. The oxymyoglobin at the surface is often oxidized to metmyoglobin, thereby giving the product a brown color (see Chapter 13 for discussion on meat color). Lower temperatures can help reduce heme oxidation (Froning, 1981). Calcium level also significantly increased by raising the deboner head pressure (Table 6.3). In many countries, the amount of bone fragments, measured as calcium content, in the meat is regulated. The U.S. regulations require that no more than 1% bone particles be present in the product. Therefore, a machine should be adjusted so as not to operate at a level producing more than 1% calcium. In addition to percentage of bone, particle size is also of great importance, because large particles might cause a gritty texture and potential dental problems. Therefore, bone size is regulated in places like the United States, where 90% of the bone particles cannot exceed 0.5 mm and no particle should be larger than

Table 6.3. Effect of Deboner Head Pressure on the Chemical Composition and Yields of Mechanically Deboned Whole Roaster Breasts (Bone In, Skin On) vs. Composition of Meat Obtained by a Hand-Deboned Meat Operation. Adapted from Barbut et al. (1989).

Pressure (lb/in^2)	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Calcium (ppm)	Iron (ppm)	Palmetic[a] (%)	Yield (%)
Mechanically deboned								
40	69.82[b]	20.65[b]	8.13[b]	1.05[cd]	582[c]	10.00[c]	23.0[bc]	45
75	70.37[b]	20.76[b]	7.88[b]	1.04[cd]	534[c]	11.70[c]	22.8[bc]	44
120	70.28[b]	20.10[b]	8.47[b]	1.12[bc]	568[c]	10.60[c]	24.7[bc]	42
150	71.05[b]	20.68[b]	6.78[c]	1.23[b]	764[b]	17.85[b]	27.3[b]	82
Hand deboned								
	73.20[c]	23.67[c]	3.10[d]	0.94[d]	164[d]	6.25[d]	20.1[c]	—

[a] Percent of total fatty acids.

[b–d] Means in the same column with different superscripts are significantly different ($P<0.05$).

0.85 mm. This regulation ensures that large bone particles, of a size that can chip teeth, are not present; however, it should be mentioned that large bone chips (<1 mm) are sometimes found in hand deboned meat. Another limitation on the use of mechanically deboned meat is in children's food, where it is limited to 20% of the product because of concern regarding excessive fluoride levels in the food. In the United States, mechanically deboned meat is not allowed in baby food.

The microbial quality of the meat is also of importance, because the meat can quickly deteriorate if the product is not handled properly. It is recommended that backs, necks and frames, used as raw material for mechanically deboned meat, be chilled to 4°C within an hour of hand deboning. If they are not used within 72 hours, they should be frozen at -18°C (USDA, 1994). The mechanically deboned meat recovered should be used within 24 hours of the separation process, otherwise the meat should be frozen. It should be noted that during the mechanical deboning process, the temperature will rise due to the high friction exerted within the deboning head (e.g., 1–6°C during grinding and 5–7°C during deboning). This temperature rise requires effective chilling during or after the deboning process to minimize microbial growth. Chilling can be done by mechanical refrigeration or cryogenic agents such as liquid nitrogen or CO_2. The latter two are very effective (see Chapter 7) and can be added/sprayed directly onto the product; however, some reports have suggested that CO_2 might contribute to more lipid oxidation if the meat is frozen and stored for over six months. Another factor contributing to higher rates of microbial degradation is the mixing of exposed surfaces tissue (that is more contaminated) with cleaner internal tissue; therefore, every effort should be made to keep low microbial counts.

The fat level in the final mechanically deboned meat product is determined by the type of raw materials used (e.g., with/without skin, part location). In the United States, there are two categories of mechanically deboned meat. The first has a maximum fat limit of 30% and a minimum protein content of 14%. The second does not have fat or protein limits, but it is to be used in a meat product that has inspection limits.

Two more recent developments in the harvesting of mechanically deboned meat include the development of deboners that can yield a product with a more meat-like texture and the development of surimi-type meat products. Enhancing the texture of mechanically deboned meat can be done by machines that cause less cellular disruption and leave "more structure" in the final product. The surimi-like products are based on the old Japanese technology that refers to washing minced fish meat. The washing process removes substantial quantities of enzymes, fat and heme pigment from the myofibrillar proteins. The final product is generally whiter in color and possesses very good gelation and binding characteristics. In the fish industry, minced and washed meat is made into surimi-type products that include different seafood

Table 6.4. Carcass Weights and Portion Characteristics of High-Yield Broiler Chickens (% Carcass Weight). From Leeson and Summers (1997). With Permission.

Weeks of Type	Liver Weight (g)	Carcass Weight (g)	Abdominal Fat Pad	Wings	Drums	Thighs	Bone-in Breast	Deboned Breast
Male								
4	1,224	818	2.5	10.2	14.8	17.6	29.4	18.5
5	1,754	1,237	2.6	10.4	13.3	17.0	30.1	19.8
6	2,223	1,596	3.3	9.7	13.1	16.3	31.2	20.1
7	2,666	1,982	3.3	9.7	13.6	16.2	31.4	20.5
8	3,274	2,500	3.4	9.4	13.5	16.5	32.5	21.6
9	3,674	2,731	4.2	10.9	16.1	19.7	36.0	23.6
10	4,293	3,320	3.7	9.2	13.3	17.9	32.2	21.8
Female								
4	1,088	720	2.8	10.8	14.4	17.5	29.5	20.4
5	1,582	1,160	3.2	9.8	12.2	16.6	29.7	19.5
6	1,910	1,376	3.4	10.7	13.4	16.4	31.5	21.5
7	2,382	1,753	4.3	9.8	13.8	16.5	32.5	21.7
8	2,730	1,996	4.3	9.6	13.0	16.6	34.2	22.6
9	3,125	2,393	4.8	9.5	13.2	17.7	33.6	22.1
10	3,546	2,660	5.4	9.1	12.2	17.1	34.3	23.4

analogues such as imitation shrimp, crab leg, etc. The initial raw material that is used for surimi is not suitable for human consumption (e.g., high content of small bones). So it is harvested, mechanically deboned, washed and then processed in a special way to form a muscle-like texture (i.e., extruded in a string-like configuration and later twisted together to form a rope-like structure). There have been some reports describing the washing process of mechanically deboned meat obtained from poultry. Dawson et al. (1989) investigated the use of several washing solutions such as tap water, phosphate buffer, 0.1 M sodium chloride and 0.5% sodium bicarbonate. Sodium bicarbonate was the most effective in removing heme proteins and increasing the lightness of the washed meat. The washed meat was found to have very good gelation properties and had a light color resembling white breast meat.

Yield

The expected yields from live poultry and subsequent cut-up parts are very important to the industry. As described in Chapter 1, the past few decades have been devoted to massive selection for fast-growing meat-producing birds. Table 6.4 provides an example of yield averages for a fast-producing broiler line over the period of four to 10 weeks of age. As indicated before,

Table 6.5. Mean (SE) Weight of the Live Weight, Carcass Weight and Weight of By-Products of Ostriches and Rheas. Adapted from Morris et al. (1995) and Sales et al. (1997), respectively.

	Ostrich[a]		Rhea[b]	
Parts	kg	% of Live Weight	kg	% of Live Weight
Live weight	95.54 (2.55)		24.72 (1.05)	
Carcass weight	55.91 (1.64)	58.59	15.20 (0.77)	61.39
Lean meat	31.10 (0.32)	35.7	9.50 (0.48)	38.8
Fat	5.0 (0.17)	5.2	1.6 (0.25)	6.6
Feathers	1.74 (0.13)	1.85	0.41 (0.02)	1.64
Blood	2.98 (0.37)	3.11	1.09 (0.07)	4.4
Wings	0.74 (0.06)	0.78	0.72 (0.02)	2.88
Feet	2.51 (0.16)	2.64	0.89 (0.03)	3.62
Skin	6.71 (0.25)	7.04	0.97 (0.04)	3.9
Heart	0.94 (0.05)	0.99	0.29 (0.01)	1.15
Empty gizzard + crop	2.15 (0.09)	2.26	0.66 (0.01)	2.67
Liver	1.42 (0.08)	1.49	0.51 (0.01)	2.07

[a] Fourteen ostriches in the age range 10–14 months.

[b] Three *Rhea americana* and five *Pterocnemia pennata* in age range 11–12 months.

the usual marketing time for broilers is seven weeks of age. Breast meat yield for males and females reaches about 31% for bone-in and 20% for boneless portions. For wings, drums and thighs, the yields in both males and females was 10, 14 and 16%, respectively. However, at seven weeks of age, the male carcass weighs about 15% more than the female, meaning that on a weight basis, the processor gets more meat. In turkeys, the differences in body weight between males and females are more pronounced, and therefore, marketing age can vary by as much as one month. For ratite meat (e.g., ostrich, rhea), the yield values are lower (Table 6.5). One of the reasons might be that they have not been domesticated as much as chickens and turkeys. However, ratite meat is receiving much more attention today, and producers are developing markets for the meat and its by-products. An example of a meat-cutting/splitting process, used in Australia, is shown in Figure 6.13. In contrast to other poultry, ratite meat is commonly sold as individual muscles (Sales et al., 1997) and not as cuts consisting of several muscles.

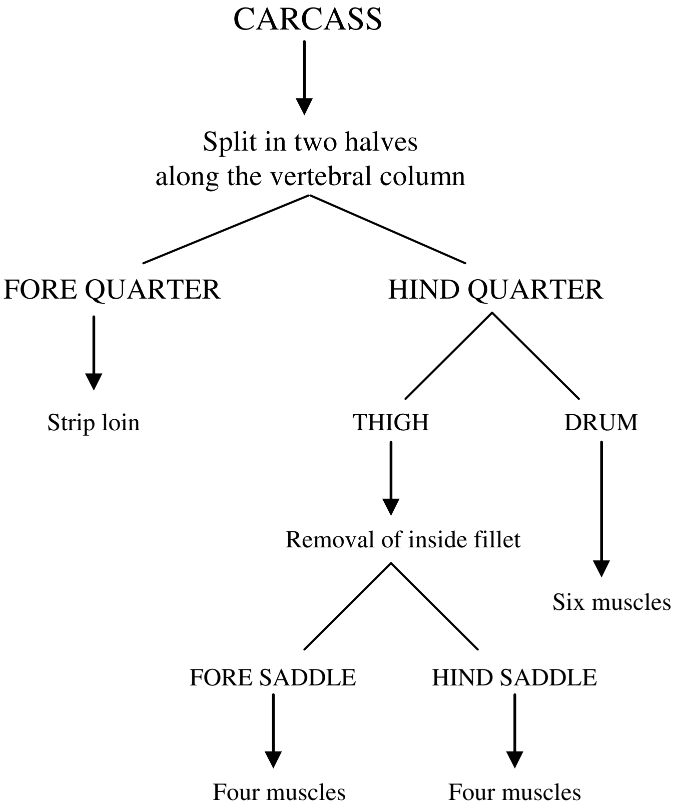

Figure 6.13. *Breakdown of an Emu Carcass as Outlined by the Australian Quarantine and Inspection Services.*

COMPOSITION

Poultry meat is widely accepted as a good source of high-quality protein, the B vitamins and minerals. The fact that poultry meat is considered to be a good source of lean meat has resulted in a significant increase in poultry meat consumption around the world (see Chapter 1). Overall, the composition of poultry meat is dependent on the kind, class, sex, age and diet. Table 6.6 shows meat composition of selected cuts and illustrates the differences among various species. Turkey meat is usually lower in fat than chicken, while goose and duck meat are higher in fat. When skin is present, the fat level is higher because skin includes subcutaneous (under the skin) fat. When fat content goes up, moisture is reduced (Table 6.6), and, therefore, it is commonly said that there is an inverse relationship between moisture and fat content. The protein content is not affected as much by this change. Higher fat also translates to a higher caloric value, but in general, poultry is considered to be a lean meat when compared to red meat sources. Another important difference is that poultry fat is less saturated than beef and pork fat (Table 6.7) and, therefore, has a more favorable image. The higher unsaturation also results in a lower melting point of the fat (Table 6.8). This also has implications regarding fat stability to lipid oxidation (i.e., a higher degree of unsaturation makes the fat less stable) and allowable chopping temperature when preparing a meat emulsion (see Chapter 9). Overall, poultry meat consumers can obtain a very lean

Table 6.6. Composition and Nutritional Value of Different Raw Poultry Meats. From USDA (1999b).

Source of Meat			Water	Protein	Fat	Ash	Iron	Calories
Species	Meat	Skin	%	%	%	%	(mg)	(kcal)
Chicken	White	+	68.6	20.3	11.1	0.86	0.8	186
		−	74.9	23.2	1.6	0.98	0.7	114
	Dark	+	65.4	16.7	18.3	0.76	1.0	237
		−	75.9	20.1	4.3	0.94	1.0	125
Turkey	White	+	69.8	21.6	7.4	0.90	1.2	159
	White	−	73.8	23.5	1.6	1.00	1.2	115
	Dark	+	71.1	18.9	8.8	0.86	1.7	160
	Dark	−	74.5	20.1	4.4	0.93	1.7	125
	All	+	70.4	20.4	8.0	0.88	1.4	160
Duck	All	+	48.5	11.5	39.3	0.68	2.4	400
Goose	All	+	50.0	15.9	33.5	0.87	2.5	370
	All	−	68.3	22.7	7.1	1.10	2.5	160
Quail	All	+	69.7	19.6	12.1	0.9	3.9	192
Pheasant	All	+	67.7	22.7	9.3	1.3	1.1	180
Pigeon	All	+	56.6	18.5	23.8	1.4	—	294

Expressed on a 100 gram portion of meat with/without skin.

Table 6.7. Fatty Acid Composition of Fat Deposits Associated with Skin (Poultry) and Subcutaneous Tissue (Beef and Pork). Adapted in Part from Hedrick et al. (1994).

		% Fatty Acid in Fat		
Fatty Acid	Formula	Chicken	Beef	Pork
Palmitic[a]	C16:0	26	27	28
Stearic[a]	C18:0	7	21	12
Palmitoleic	C16:1 (9c)	7	2	3
Oleic	C18:1 (9c)	20	42	47
Linoleic	C18:2 (9c, 12c)	21	2	6
Linolenic	C18:3 (9c, 12c, 15c)	—	0.5	0.7
Arachidonic	C20:4 (5c, 8c, 11c, 14c)	0.6	0.4	0.8
% Saturated		33	54	42
% Unsaturated		67	46	58

[a] Examples of unsaturated fatty acids. (Note: the other fatty acids are unsaturated; only major fatty acids are listed in the table).

product by excluding the skin because, unlike red meat animals, most of the fat is subcutaneous (e.g., there is no marbling and minimal intramuscular fat in chicken breast meat).

Broiler Chicken Meat Composition and Cooking Yield

The general composition of chicken meat is shown in Table 6.6. More detailed nutritional composition data for raw light chicken meat with skin are

Table 6.8. Effect of Fatty Acid Composition and Saturation/Unsaturation on Melting Point.

Acid	Formula[a]	Molecular Weight	Melting Point
Butyric	C4:0	88	−5.3°C
Caproic	C6:0	116	3.2°C
Caprylic	C8:0	144	16.5°C
Lauric	C12:0	200	44.8°C
Palmitic	C16:0	256	62.9°C
Stearic	C18:0	284	70.1°C
Oleic	C18:1	282	16.3°C
Linoleic	C18:2	280	−5.0°C
Linolenic	C18:3	278	−11.0°C

[a] Fatty acid chemical formulas ending with a “0” are saturated; those ending with a “1” have one double bond; and those ending with a “2” have two double bonds, etc.

shown in Table 6.9. Overall, white chicken meat is very high in protein, 20 to 23%, with and without skin, respectively. When the skin is removed, the fat level drops from about 11% to 1.6%.

Cooking methods affect the chemical composition in different ways. While roasting results in the highest protein content (29%; Table 6.9), stewing and frying also result in elevated protein content due to moisture and fat loss (or protein concentration). Stewing results in a more moist product compared to

Table 6.9. Effect of Three Different Cooking Methods on the Nutritional Composition of Light Chicken Meat with Skin. From USDA (1999b)

Nutrients and Units		Mean Values in 100 Grams, Edible Portion			
		Raw	Fried[a]	Roasted	Stewed
Proximate:					
Water	g	68.6	50.23	60.51	65.13
Food energy	kcal	186	277	222	201
Protein (N × 6.25)	g	20.27	23.55	29.02	26.14
Total lipid (fat)	g	11.07	15.44	10.85	9.97
Carbohydrate, total	g	0	9.5	0	0
Ash	g	0.86	1.29	0.93	0.78
Minerals:					
Calcium	mg	11	20	15	13
Iron	mg	0.79	1.26	1.14	0.98
Magnesium	mg	23	22	25	20
Phosphorus	mg	163	168	200	146
Potassium	mg	204	185	227	167
Sodium	mg	65	287	75	63
Zinc	mg	0.93	1.06	1.23	1.14
Copper	mg	0.04	0.061	0.053	0.044
Manganese	mg	0.018	0.055	0.018	0.018
Vitamins:					
Ascorbic acid	mg	0.9	0	0	0
Thiamin	mg	0.059	0.113	0.06	0.041
Riboflavin	mg	0.086	0.147	0.118	0.112
Niacin	mg	8.908	9.156	11.134	6.935
Pantothenic acid	mg	0.794	0.794	0.926	0.535
Vitamin B_6	mg	0.48	0.39	0.52	0.27
Folacin	mcg	4	6	3	3
Vitamin B_{12}	mcg	0.34	0.28	0.32	0.2
Vitamin A	IU	99	79	110	96
Lipids:					
Saturated, total	g	3.16	4.12	3.05	2.8
12:0	g	0.01	0.01	0.01	0.01
14:0	g	0.09	0.09	0.09	0.08
16:0	g	2.33	2.76	2.25	2.07
18:0	g	0.63	1.2	0.62	0.56

(continued)

Table 6.9. (continued)

Nutrients and Units		Mean Values in 100 Grams, Edible Portion			
		Raw	Fried[a]	Roasted	Stewed
Monounsaturated, total	g	4.52	6.37	4.26	3.92
16:1	g	0.6	0.45	0.57	0.53
18:1	g	3.74	5.79	3.51	3.23
20:1	g	0.12	0.09	0.12	0.11
Polyunsaturated, total	g	2.34	3.6	2.31	2.12
18:2	g	2.07	3.24	1.98	1.83
18:3	g	0.10	0.18	0.09	0.08
18:4	g	—	—	—	—
20:4	g	0.06	0.07	0.09	0.08
20:5	g	0.01	0.01	0.01	0.01
22:5	g	0.01	0.01	0.02	0.02
22:6	g	0.02	0.02	0.03	0.03
Cholesterol	mg	67	84	84	74
Amino Acids:					
Tryptophan	g	0.227	0.268	0.326	0.294
Threonine	g	0.839	0.963	1.202	1.084
Isoleucine	g	1.015	1.171	1.458	1.316
Leucine	g	1.477	1.723	2.119	1.91
Lysine	g	1.654	1.841	2.374	2.142
Methionine	g	0.541	0.616	0.776	0.699
Cystine	g	0.27	0.326	0.385	0.347
Phenylalanine	g	0.788	0.938	1.13	1.019
Tyrosine	g	0.655	0.762	0.94	0.848
Valine	g	0.985	1.147	1.412	1.273
Arginine	g	1.268	1.445	1.811	1.629
Histidine	g	0.597	0.682	0.858	0.774
Alanine	g	1.177	1.334	1.679	1.509
Aspartic acid	g	1.807	2.04	2.587	2.33
Glutamic acid	g	2.967	3.75	4.254	3.835
Glycine	g	1.291	1.466	1.823	1.629
Proline	g	0.973	1.238	1.381	1.238
Serine	g	0.714	0.869	1.021	0.919

[a] Battered (22%) and fried.

roasting due to the cooking medium that reduces cooking losses. However, as discussed in Chapter 9, protein denaturation during the cooking process results in lower water-holding capacity.

Frying the product, after it has been battered and breaded (22% coating in the example provided in Table 6.9), raises the carbohydrate content from 0 to 9.5% and the fat content from 11 to 15.4%. The proportion of saturated fatty acids also increases. The cholesterol level was similar to that of the roasting method because, in this case, a vegetable oil (i.e., no cholesterol) was used.

Heat-sensitive vitamins such as ascorbic acid can be significantly reduced by cooking.

The amino acid profile is typical of lean meat composition.

Meat yields obtained by two common cooking methods are reported in Table 6.10. The values are averages and should be viewed as such. Variations within the same cooking method (e.g., higher/lower temperature, more/less time), previous treatment(s) of the meat (e.g., marination) and processing history (e.g., freezing, chilling) can affect cooking yields. Therefore, where precise values are required, it is recommended that a reference to a specific cooking procedure be used or a small experiment be conducted.

Turkey Meat Composition

The composition of turkey meat is shown in Table 6.6. Overall, the composition (per 100 g edible portion) is fairly similar to broiler meat. However, turkeys are bigger and produce more meat, and the ratio of skin to meat is lower than in broilers (i.e., proportionally, there is less skin per lean meat mass). This can be seen in comparing the skin-on light turkey meat (7.4% fat) and chicken meat (11.1%). The same is true for dark meat (8.8 vs. 18.3%, respectively). Average cooking yields for young turkey hens and toms are

Table 6.10. Average Yields for Cooked Poultry. From USDA (1999b).

Product	Cooking Method	Meat	Part[a] with Bone	Meat[b] Only	Meat[c] and Skin
Chicken					
Broiler	Roasted	all	66	77	65
		light	68	73	68
		dark	64	75	63
	Stewed	all	75	79	73
		light	78	80	77
		dark	73	78	69
Turkey					
Young hen	Roasted	all	73	77	74
		light	76	81	78
		dark	70	72	70
Young tom	Roasted	all	72	72	71
		light	73	76	73
		dark	70	67	67

[a] As % of raw part with bone.

[b] As % of raw meat without skin.

[c] As % of raw meat, skin and separable fat.

provided in Table 6.10. They are higher than chicken because the ratio of bone to meat is lower in larger birds.

Duck Meat Composition

The composition of duck meat is shown in Table 6.6. Overall, duck meat is fattier than broiler and turkey meat. One of the reasons is the limited selection for leaner ducks, and the other is the environment in which ducks live (i.e., water which requires more insulation). Iron content is also higher (i.e., higher heme pigment) and therefore, the meat appears much darker than chicken and turkey meat.

Modifying Fatty Acids

The diet of the monogastric birds can significantly affect the composition of the meat. Carcass fat content and composition are particularly sensitive to the type of feed. In general, high-energy diets or low-protein diets have been shown to increase carcass fat. It is also possible to modify the fatty acid content in poultry meat by manipulating the fat source in the diet (Yau et al., 1991). Over the past decade, an increased interest in producing meat with an appealing nutritional profile has resulted in studying the effects of incorporating more unsaturated fat, particularly, omega-3 fatty acids. These acids have been reported to assist in the prevention of vascular diseases and some immunological disorders and are also important in early neural development. In trying to increase omega-3 fatty acids in chicken meat, flaxseed and menhaden oil are ingredients commonly considered; however, α-linolenic acid deposition results from feeding the former, while the omega-3 fatty acid level responds to feeding materials such as menhaden oil. Any omega-3 fatty acid deposition is usually proportional to its dietary concentration, although the incorporation of omega-3 fatty acids into poultry meat is a gradual process. Gonzalez-Esquerra and Leeson (2000) have shown that linolenic acid was preferentially deposited in dark meat, and long-chain omega-3 fatty acids were preferentially deposited in white meat. Breast meat sensory quality was not affected in birds given 100 g/kg flaxseed for 14 days (treatment a), 7.5 g/kg menhaden oil for 14 days (treatment b) or 100 g/kg flaxseed +0.75 g/kg menhaden oil for seven days (treatment c). In contrast, thigh meat sensory quality decreased in treatments b and c suggesting that excessive levels can decrease sensory acceptability. Feeding flaxseed and menhaden oil to birds for just seven days prior to slaughter resulted in significant enrichment of omega-3 fatty acids, depending on their dietary concentrations. Overall, the linolenic acid and long-chain omega-3 fatty acids showed preferential deposition in dark and white meat, respectively, which may affect the sensory quality of various portions differently.

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CHAPTER 7

Preservation by Chilling, Heating and Other Means

INTRODUCTION

STORING meat after slaughter represents a challenge to meat processors, retailers and the consumer. Fresh meat is perishable because it contains most nutrients required by bacteria, the pH is not prohibitive to most bacteria and it has abundant amounts of free water. If proper storage conditions (e.g., refrigeration) or preservation treatments (e.g., heating, irradiation) are not employed, the meat will spoil within a matter of hours or days. In areas where refrigeration is not available, poultry is still marketed live and slaughtered immediately prior to consumption. In other places, special procedures are used (e.g., HACCP; see Chapter 12) to ensure low microbial counts and consumer safety. The rules and regulations are usually enforced by special government agencies designed to supervise meat production and assure wholesomeness (see Chapter 6; Inspection).

The history of food preservation employed by humans is fairly old. Thousands of years ago, people had already used different techniques without actually understanding the scientific principal behind them. Some historians describe two major periods in terms of food consumption. The first is called the food-gathering period that covers the time from human origin, over one million years ago, to 8,000–10,000 years ago. The second is called the food-producing period that continues until today (Jay, 2000). It appears that food spoilage problems were encountered early in the second period when people started to produce and store their own food for extended periods of time. Spoilage problems caused by improper storage as well as disease transmission via food have required some innovations/solutions. Drying food was one of the earliest methods employed to store foods like grain and fruits and was also used to preserve slices of meat. Sun-dried grain and meat could be stored for extended periods of time. Some cultures discovered that drying and smoking meat over fire could substantially extend the shelf life of the product. Later, fermentation of grains resulted in the production of beer, which can be traced back to ancient Babylonia at around 7000 BC. Other people, such as the Samaritans, are believed to have been the first great livestock breeders and dairymen, who were among the first to make butter at about 3000 BC. They were also known to use salted meat, fish and dried skins. The early Egyptians in 3000 BC were known for their ability to ferment dairy products and make cheeses. Salted meat was known to be used by the Israelites, the Chinese and the Greeks; the latter also passed it to the Romans. Evidence of sausage fermentation by the ancient Babylonians and the ancient Chinese people goes as far back as 1500 BC. It is doubtful whether people at that time understood the nature of food preservation by fermenting microorganisms; however, they used it fairly successfully. It was probably common to "seed" a new batch with material from a successfully previous batch and by that transmit the "right culture" to reduce chances of spoilage. It is also doubtful whether people fully understood the role of food in transmitting diseases or the danger of eating meat from infected animals. Advances in understanding food poisoning and spoilage were essentially made within the first millennium AD (Jay, 2000). Concern over meat butchers is mentioned for the first time in documents regarding Swiss butchers handling marketable and nonmarketable meat in 1156. In 1276, a compulsory slaughter and inspection order was issued for abattoirs in Augsburg. Although people were aware of quality attributes of meat by the 13th century, it is doubtful that there was any knowledge of the actual causal relationship between meat quality and microorganisms. One of the first people to suggest the role of bacteria in spoilage of food was a monk by the name of A. Kircher, who examined decaying carcasses and milk, and referred to "worms" invisible to the naked eye. His observations did not receive wide acceptance, and in 1765, L. Spallanzani showed that beef boullion that had been boiled for an hour, and sealed, remained sterile and did not spoil. His experiment was designed to disprove the spontaneous generation of life theory. In any case, his experiment did not convince critics, because they thought that the exclusion of oxygen was vital to spontaneous life generation. Only a hundred years later, Schwann repeated a similar experiment, but allowed sterile air to be supplied (by passing through a heated coil) and demonstrated no spontaneous life generation.

One of the most important events in food preservation occurred about 200 years ago when Francois Appert succeeded in preserving meat in glass jars after keeping it in boiling water for extended periods of time. His discovery of the canning process occurred in 1795 as a result of the French government prize offer of 12,000 Francs for discovering a practical method for food preservation. In 1810, Appert was issued a patent for his process. This discovery actually precedes Lois Pasteur by about 50 years. Pasteur, who is considered the father of modern microbiology, demonstrated the role of bacteria in the spoilage of French wines and suggested ways to prevent contamination/recontamination and spoilage. The process developed by Pasteur is now known as pasteurization.

It is also interesting to note that some of the common processes used today to preserve food are fairly modern (Jay, 2000):

- Commercial canning started in the early 1800s.
- The first extensive use of ice in transporting meat by sea began in 1774.
- The first successful cargo of frozen meat was sent from Australia to England in 1878.
- Commercial pasteurization of milk started in the United States in 1890.
- Mechanical refrigeration for fruit storage began in Chicago in 1890.
- Sodium benzoate was given an official sanction as a preservative in 1908 in the United States.
- Quick freezing of food was developed in Germany by 1916.
- In 1920, first publication, by Bigelow and Esty, describing the systematic study of spores and heat resistance at about 100°C appeared.
- The "general method" for calculating thermal processes was published in 1923.
- The first commercial use of controlled-atmosphere storage of apples was made in Europe in 1928.
- A patent that proposed using high-energy radiation for processing foods was issued in 1929 in France.
- The first application of ionizing radiation to preserve hamburger meat was made in 1943 by B. Proctor in the United States.
- The *D*-value concept (for microbial lethality; see Chapter 11) came into general use in 1950.
- The antibiotic nisin was patented in 1954 in the United Kingdom for use in certain processed cheese to control clostridial defects.
- Sorbic acid was approved for use as a food preservative in the United States in 1955.
- The antibiotic chlortetracycline was approve for use in fresh poultry in 1955. Oxytetracycline followed in 1955, and approval was rescinded in 1966.
- The first commercial food irradiation facility was planned and designed in the United States in 1967 (the second became operational in 1992 in Florida).
- Nisin was accorded GRAS status on 1988 in the United States.
- Irradiation of poultry was approved in the United States in 1990.

The following chapter will describe various means of preservation and some equipment used to preserve food with emphasis on poultry meat. In addition, the reader is referred to Chapter 11, which is devoted to microbiology and sanitation. Useful information on the hazard analysis critical control point (HACCP) system used for poultry processing can be found in Chapter 12.

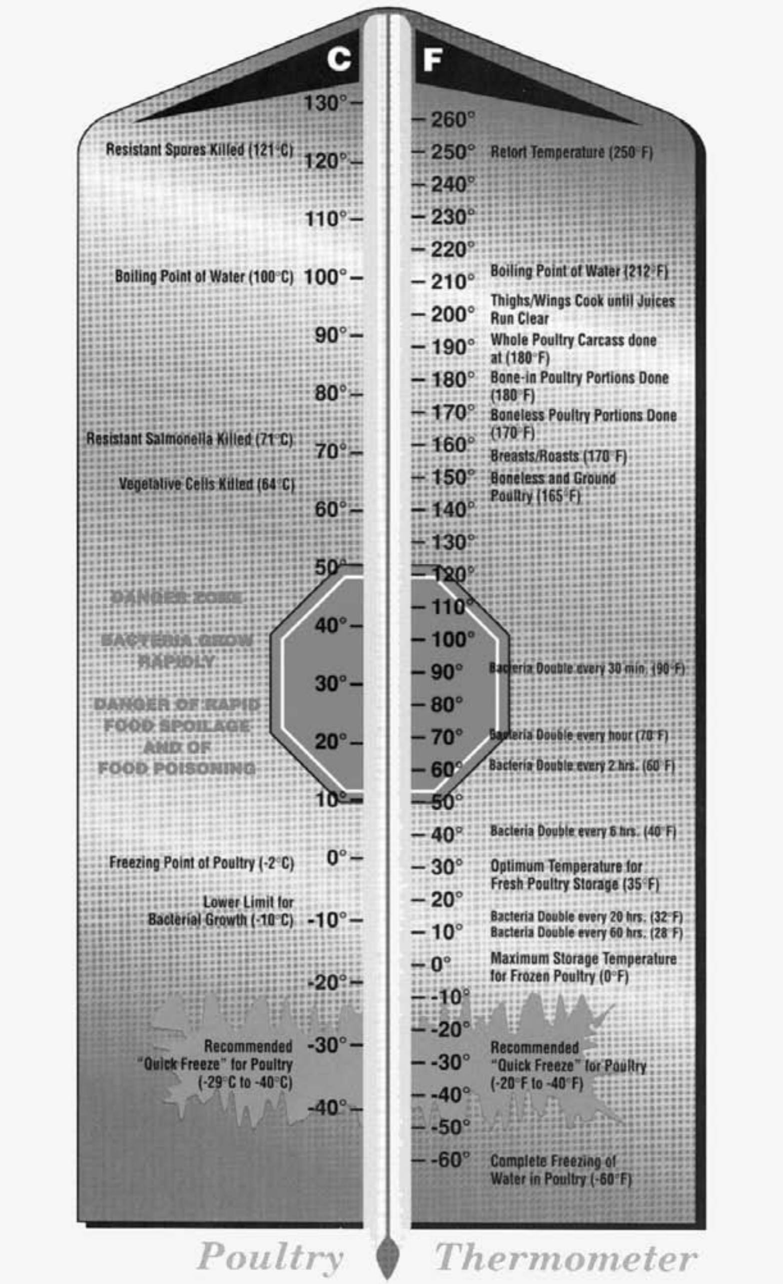
PRESERVATION BY LOW TEMPERATURE (CHILLING, FREEZING)

Refrigeration, preservation by low temperature, is the most common way of extending the shelf life of fresh meat. Poultry carcasses are commonly chilled by water immersion or cold air immediately after evisceration (see Chapter 4). This process allows the removal of body heat from around 39°C to about 5°C within a few hours. The rate of temperature decline during the process depends on factors such as the size of the bird, chilling method, amount of insulating fat, refrigeration facility and the amount of product moving through the system. Certain countries regulate the time allowed to achieve a certain final temperature. In the United States, for example, the requirement is to get to 5°C or lower within 8 hours after slaughter. In many of the processing plants, this temperature is achieved in less than 8 hours. One potential problem associated with chilling the meat too fast is cold-shortening, which was described in Chapter 2. In most cases concerning commercial chilling of chicken and turkey, the time interval between slaughter and chilling is usually sufficient to prevent toughening associated with cold-shortening. Proper chilling of the meat effectively helps in reducing the rate of microbial growth. Figure 7.1 shows the temperature growth range of microorganisms that might cause spoilage or food poisoning (for a discussion on psychrophiles, mesophiles and thermophiles, see Chapter 11). It also shows the safe ranges in which to store food.

In some operations, poultry carcasses are cut and deboned within 4–6 hours after slaughter, and then the meat is allowed to further cool in a refrigerator. In such a case, attention should be given to allow enough spacing between the parts (positioned on trays or in boxes) so cold air movement will not be restricted, and the desired chilling rate will be achieved. Special palettes and boxes are available to allow good air movement and eliminate problems of insulated areas not adequately exposed to cold air. The relative humidity in the cooler is usually kept high so as to minimize shrinkage due to high evaporation losses resulting from cold air blowing over an unwrapped product.

The shelf life of refrigerated poultry carcasses or parts is generally limited to 5–12 days. The length of time depends on factors such as initial contamination load, storage temperature, temperature fluctuation over the storage period and packaging conditions including modified atmosphere. During the storage of fresh meat, temperature is one of the major factors in determining the shelf life. Storing the meat at −2° to 0°C will result in a significantly prolonged shelf life compared to storing the meat at 4° to 6°C. For additional discussion, see Chapter 11.

Freezing is considered a very good method for preserving poultry meat for an extended period of time. However, it should be realized that frozen poultry undergoes some chemical changes that limit the storage life of the product. Even under the best frozen conditions, it is not suggested that poultry meat be stored for over one year.



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Resistant Spores Killed (121°C)
Boiling Point of Water (100°C)
Resistant Salmonella Killed (71°C)
Vegetative Cells Killed (64°C)
DANGER ZONE
BACTERIA GROW RAPIDLY
DANGER OF RAPID FOOD SPOILAGE AND OF FOOD POISONING
Freezing Point of Poultry (-2°C)
Lower Limit for Bacterial Growth (-10°C)
Recommended "Quick Freeze" for Poultry (-29°C to -40°C)
Retort Temperature (250°F)
Boiling Point of Water (212°F)
Thighs/Wings Cook until Juices Run Clear
Whole Poultry Carcass done at (180°F)
Bone-in Poultry Portions Done (180°F)
Boneless Poultry Portions Done (170°F)
Breasts/Roasts (170°F)
Boneless and Ground Poultry (165°F)
Bacteria Double every 30 min. (90°F)
Bacteria Double every hour (70°F)
Bacteria Double every 2 hrs. (60°F)
Bacteria Double every 6 hrs. (40°F)
Optimum Temperature for Fresh Poultry Storage (35°F)
Bacteria Double every 20 hrs. (32°F)
Bacteria Double every 60 hrs. (28°F)
Maximum Storage Temperature for Frozen Poultry (0°F)
Recommended "Quick Freeze" for Poultry (-20°F to -40°F)
Complete Freezing of Water in Poultry (-60°F)
Poultry Thermometer

Figure 7.1. *Microorganism Growth and Recommended Poultry Meat Storage Temperatures. From NAMP (1999). With Permission.*

Suggested times for storing poultry meat are as follows (Hedrick et al., 1994):

Temperature	Time
−12°C	2 months
−18°C	4 months
−24°C	8 months
−30°C	10 months

Overall, extending the storage life can be achieved by lowering the freezing temperature. This also reduces the rate of chemical deterioration, mainly oxidative rancidity, which results in off-flavor development (described by some consumers as an old, stale and cardboard-like aroma). Other changes might result from protein denaturation that can cause textural changes (i.e., toughening) of the meat. Freezing rate has a strong effect on the texture because slow freezing results in large ice crystal formation, while fast freezing results in small crystals. Formation of large crystals is more damaging to the cellular and membranous structures of the muscle. Fast or quick freezing refers to a process where the temperature is lowered to about −20°C within 30 minutes. This can be achieved by direct immersion in a very cold medium, indirect contact of the meat with a cold refrigerant or air blasts of frigid air across relatively small portions of the meat. Slow freezing refers to a process whereby the desired temperature is achieved within 3–72 hours. Fast freezing is advantageous in maintaining the product's quality but is substantially more expensive. Fast freezing results in small ice crystal formation that causes less damage to the muscle cell structure. The damage is only seen later, during thawing, where less drip loss is exudating the product compared to poultry frozen at a slow rate.

From a microbiological standpoint, quick freezing does not allow microorganisms to adapt to the fast decline in temperature and, thus, causes a greater thermal shock to the bacteria as opposed to slow freezing. However, slow freezing can be more damaging to microorganisms because they are exposed to adverse or injurious factors for a longer period of time.

It should be remembered that freezing does not kill all the microorganisms and does not result in sterilization of the food. As a matter of fact, quite a few microorganisms can survive the process (even if some will be injured) and grow after thawing. The meat and other industries are using frozen cultures, such as *lactobacilli,* for the fermentation of meat, dairy and other products. For such an application, the cultures are frozen under ideal conditions to minimize damage to the cells.

Common freezing methods used by the poultry industry include still air, blast freezing, plate freezing, liquid immersion/spray and cryogenic freezing. Figure 7.2 shows the relative freezing rate by using some of the methods. It is important to note that during slow freezing, the time allowed for ice crystal for-

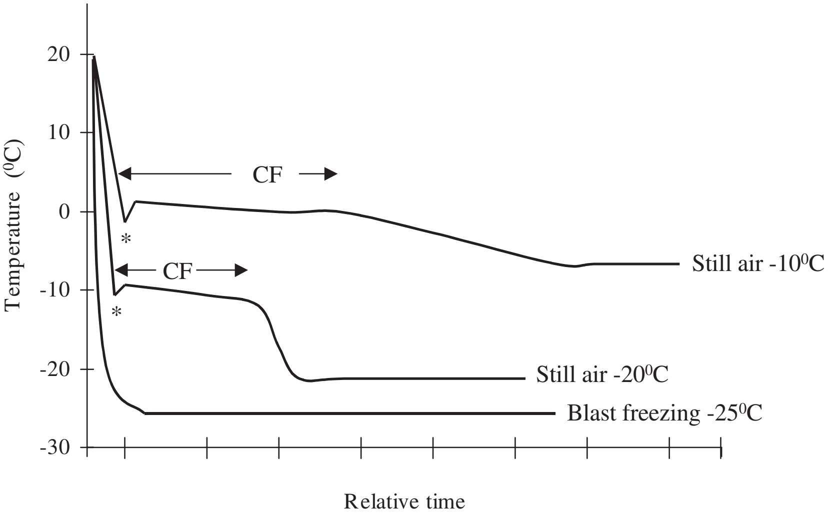


Figure 7.2. *Effect of Freezing Temperature on the Relative Freezing Time. CF = Crystal Formation; * Supercooling.*

mation is very long, resulting in large crystal formation. The time it takes water at 0°C to change to ice is referred to as the latent heat removal stage. At a low freezing temperature, the time to change the physical state of water from liquid to solid is shortened, and the ice crystals are formed at a lower temperature (Figure 7.2); this results in smaller ice crystal formation. Overall, poultry meat is mainly composed of water (60–75%). Water has a high specific heat (4,200 J $kg^{-1}K^{-1}$) and a high latent heat of fusion (335 kJ kg^{-1}). The energy required to freeze the meat is either supplied by melting crushed ice or by mechanical refrigeration in which electrical energy is used to compress gases (refrigerants) used to remove the heat. During the freezing operation, a characteristic curve is obtained (Figure 7.2). The food is first cooled below its freezing point, which for poultry meat is around −2°C. This is known as supercooling, and, at this point, the water still remains liquid. Then, the temperature rises back to the freezing point (or only slightly rises, but then is quickly lowered by the cryogenic medium; see Figure 7.2), and ice crystals are formed as the latent heat of crystallization is released. At this "zone," the temperature remains almost constant (Figure 7.2). At a slow freezing rate, a small number of large ice crystals are formed; whereas, during fast freezing (e.g., cryogenic), a large number of small ice crystals are formed. The rate of ice crystal growth is determined by the rate of heat transferred during the freezing process (Fellows, 1988).

At a relatively slow freezing rate, a phenomenon known as eutectic solute formation can take place. This is the result of solutes (e.g., salt) becoming supersaturated in certain areas, while the water around them freezes. This can result in the formation of high solute concentrations that exhibit a depressed freezing point. The eutectic temperature for sodium chloride is −21°C. However, it is difficult to identify individual eutectic temperatures in a complex system such as meat. Usually, commercial foods are not frozen to a temperature where all the water is frozen, and unfrozen water usually exists (about 8–9% in meat stored at −20°C).

A brief discussion of some of the common freezing methods is found below.

Still air is a slow method that is usually employed in home freezers and some large refrigerated rooms in a meat processing plant. The temperature of the freezer usually ranges between −10° to −25°C, and the heat is slowly removed from the product.

Blast freezing refers to using high-velocity, cold air, circulated by fans, to provide rapid air movement. The rate of heat transfer is greatly improved over that of still air, and the freezing rate is higher (Figure 7.2). Air velocities commonly used in commercial air-blast freezers can range from 30 to 1100 m/min, and the temperature can range from −10° to −40°C. However, air velocity of around 750 m/min and a temperature of −30°C are usually the most practical and economical conditions used by the industry (Hedrick et al., 1994). If freezing is done in large rooms, adequate spacing among boxes/pieces is extremely important to allow proper air movement at all locations. In other cases, blast tunnels are used where the meat is moving on a conveyor belt, and the dwell time is adjusted to achieve a certain freezing rate. The poultry industry uses blast-freezer tunnels, for products such as whole turkeys, in order to freeze and harden the surface and form a “crust.” The product is then packaged and transferred into a still-air or a blast-freezer chamber. Employing such quick freezing on the surface is used to achieve a lighter appearance of the whole turkey product.

Plate freezing is used for meat packaged in wrapped trays where the trays are in direct contact with metal freezer plates or shelves. The temperature of the plates can range from −10° to −30°C. Plate freezing is usually used for thinly packed fillets or ground meat patties. Heat transfer is as with still air by conduction, but the thermal conductivity of the freezer plates is much higher than air. Therefore, freezing rates are faster than in still air. Freezing rate can be increased by using colder plates, “sandwiching” the product in between two plates instead of using one plate, etc.

Liquid immersion/spray is used for cut-up poultry parts and sometimes for whole carcasses. The products to be frozen are packaged in a plastic bag and are then immersed in a freezing liquid such as a sodium chloride brine, glycol and propylene glycol. The product can also be conveyed, on a belt, through a freezing tunnel where it is continuously sprayed with a cold liquid. The length of time the product is exposed to the liquid and its temperature determine the extent of freezing. In the case of whole poultry, it is common to freeze the outside and form the so-called “crust,” and then transfer the product to a freezer room to complete the process. After the product is removed from the immersion tank or the freezing tunnel, the freezing liquid must be rinsed from the product's surface with cold water. When freezing liquid is used, attention should be given to the integrity of the packaging material to avoid any leakage problems. In any case, the freezing liquid must be nontoxic and approved by the local government. In addition, the freezing liquid selected should be relatively inexpensive, have a low freezing point and good heat conductivity.

Cryogenic freezing is performed by using liquified or condensed gases such as nitrogen (N_2) and carbon dioxide (CO_2); both can be used in liquid or vapor forms. The freezing rate is very fast, because the boiling points of liquid nitrogen and carbon dioxide are −196°C and −78.5°C, respectively. When liquid N_2 is sprayed onto food, about 48% of the total freezing capacity is taken up by the latent heat of vaporization needed to form the gas. The remaining 52% of the heating capacity (enthalpy) is available in the cold gas ,and the gas is, therefore, recirculated to achieve optimum use of its freezing capacity. Carbon dioxide has a lower enthalpy than liquid N_2, but the lower boiling point produces a less severe thermal shock. Most of its freezing capacity (85%) is available from the sublimating solid. Therefore, it is usually sprayed onto the product as fine snow that sublimates on contact, and the gas is not recirculated. Carbon dioxide consumption is usually higher than liquid N_2 consumption, but storage losses are lower. The choice of refrigeration is largely determined by the cost and nature of the product (Fellows, 1988).

In a CO_2 or N_2 freezer, the packaged or unpackaged food moves on a perforated belt through a tunnel where it is cooled by N_2 gas or dry ice. In a liquid N_2 freezer, the food is then sprayed with liquid N_2 where it can also be immersed in liquid nitrogen. The initial exposure to gases (N_2 which is driven by recirculating fans from the spraying area; Figure 7.3) reduces the thermal shock to the food. It should be remembered that using N_2 for freezing

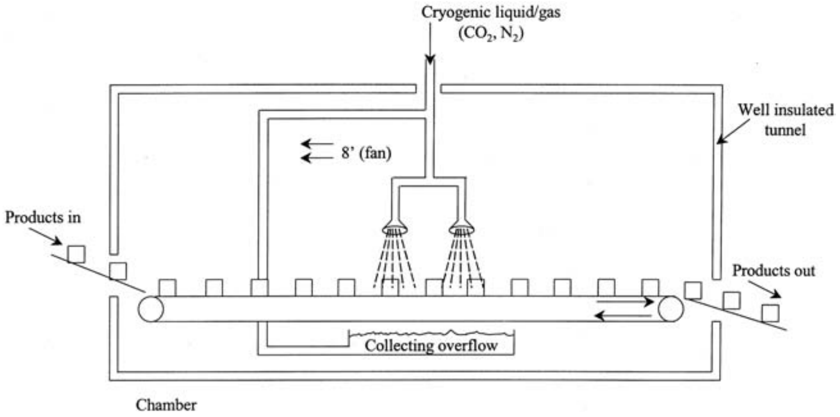


Figure 7.3. *A Schematic Diagram of a Cryogenic Freezing Tunnel. Adapted from Fellows (1988).*

results in very fast freezing (boiling point of −196°C) that can result in internal stresses (cracking or splitting) to the food. Therefore, in the poultry industry, it is common to employ N_2 freezing to small particulates, such as diced meat and nuggets, which are less susceptible to cracking. The use of rapid freezing for small particulates is called individual quick freezing (IQF). In both N_2 and CO_2 freezers, the meat's temperature is allowed to equilibrate at the desired storage temperature (commonly below −20°C) before the food is discharged from the freezer. Cryogenic freezing is used for relatively small pieces of meat (e.g., fillets) or formed products (e.g., nuggets, patties). The product can be dipped or exposed to a CO_2 or N_2 spray while moving on a conveyor belt inside an insulated tunnel (Figure 7.3). Liquid N_2 can also be used in a spiral freezer where the main advantage is employing a high freezing rate within a smaller unit. Figure 7.4 shows such a unit where a continuous mesh belt is carrying the food through the freezing chamber. Liquid nitrogen is sprayed down through the belt stack to minimize weight losses due to evaporation. The unit provides flexibility for different types of products, because dwell time can be controlled by increasing/decreasing the belt movement. Par-fried chicken nuggets (battered, breaded and fried for about 30 sec-

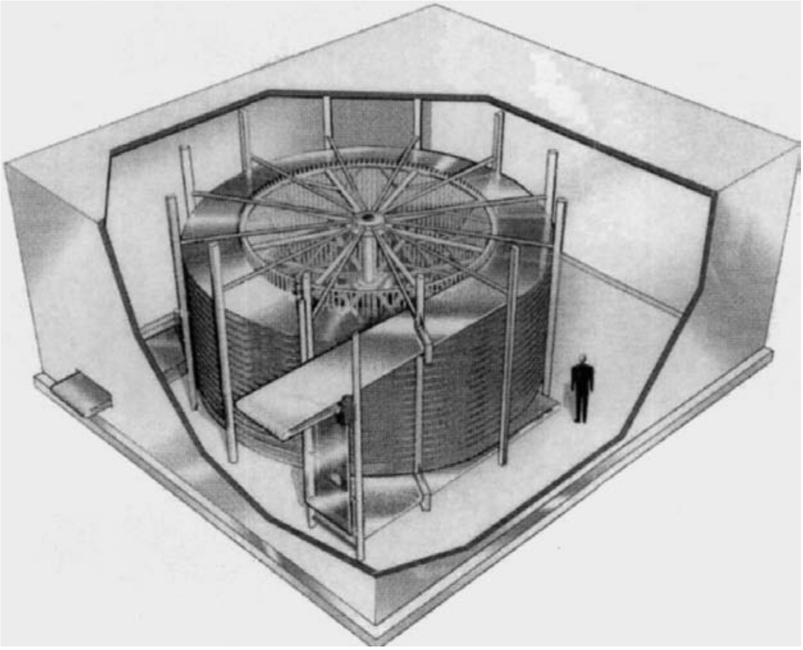


Figure 7.4. *A Large-Scale Cryogenic Spiral Freezing Unit. Courtesy of Frigoscandia Equipment, Northfield, MN, U.S.A.*

onds; see Chapter 10) can be quick frozen by this method. Cryogenic freezing provides the best way of preserving the fresh-like characteristics in a product because of the small ice crystal formation. However, it should be stressed that maintaining a low storage temperature, without much fluctuation, is of utmost importance in preserving the quality, because high freezing temperature or fluctuations will result in ice crystal growth (i.e., preferred thermodynamically) and will diminish the beneficial effect of quick freezing. When using cryogenic or regular freezing, it is important to later maintain a low and consistent frozen storage temperature. Otherwise, ice crystal growth, also called recrystallization, can occur. This will damage the texture of the food as larger ice crystals can rupture cell membranes and later result in high drip loss during thawing. Temperature fluctuation during storage causes migratory recrystallization in which the average crystal size is increasing, and the average number of crystals is decreasing. In foods, such as ice cream which is consumed frozen, this is experienced by the consumer as a “sandy” texture, in which large ice crystals cause a sandy sensation. In poultry products that are not consumed frozen, recrystallization is not felt in this way but is seen as higher drip loss and later a dryer mouth feel in the cooked product.

Cryogenic freezing is one of the most expensive methods and can be justified for high-value-added products. Various fast-food chains are currently demanding that poultry processors use cryogenic freezing for their chicken product (e.g., nuggets) in order to maintain the best possible quality. As indicated above, storage and distribution channels should also be equipped with refrigeration units that allow a low temperature without much fluctuation to be maintained.

Carbon dioxide and liquid nitrogen are also used in chilling products such as mechanically deboned meat (see Chapter 6), where temperature control during the deboning processes (i.e., using high pressure) is very important. Both cryogenic materials eventually evaporate and do not add weight to the product. Some reports have indicated that sensitive meats such as mechanically deboned meat intended for long frozen storage (>6 months) can exhibit problems if carbon dioxide is used as a result of carbonic acid formation and pH reduction, which can contribute to some lipid oxidation.

Packaging of frozen meat is very important, because meat surfaces that are exposed to cold air during storage will eventually dehydrate and result in freezer burn. The packaging material must be approved by the appropriate regulatory agency. In addition, it should exhibit strength, wet and scuffing resistance and be greaseproof. In many cases where the meat is intended for prolonged frozen storage, vacuum packaging and an oxygen barrier film are used. The removal of oxygen helps to decrease the rate of oxidation and the development of rancid off-flavor formation.

For cooked poultry products, recommended frozen storage is at ≤ -18°C, where the overall storage life depends on ingredients added and the inclusion of antioxidants. A few examples of precooked meat products are provided below (Hedrick et al., 1994).

Item	Packaged in	Max. Storage
Breaded, fried chicken	bags/aluminum pans	3 months
Steamed-cooked breaded poultry parts	bags/aluminum pans	9 months
Steamed-cooked breaded poultry parts (Treated with tripolyphosphate)	bags/aluminum pans	12 months
Sliced turkey and gravy	bags/aluminum pans	18 months

If these times are exceeded, the products will remain safe; however, flavor and odor are likely to differ from a freshly prepared product.

Bone darkening is a condition seen in young chickens after freezing. This shows as a dark/bloody appearance of the tips of the bones and muscle areas close to the bone. Myoglobin squeezed out from the bone marrow, through the relatively porous bone structure of young chickens, during the freezing process causes this. The myoglobin gives meat its red color (see Chapter 13). However, when present at the bone surface, it will turn to a dark color during cooking, and the product becomes unacceptable to consumers. Most often, this is seen around the leg, thigh and wing bones, and sometimes in the breast and backbone areas. Although it appears unappealing, the problem does not affect the safety, flavor, texture or odor of the meat.

THAWING

Thawing is the process of bringing the product back to a nonfrozen state. During thawing, the temperature rises rapidly to the near melting point and remains there throughout the relatively long course of the thawing process. This results in a longer thawing period compared to freezing (Figure 7.5) and allows more time for chemical and microbial changes. Overall, thawing is inherently slower than freezing when conducted under comparable temperature differentials. When the food is thawed, a water layer starts to form on the outside. This water layer has a lower thermal conductivity and a lower thermal diffusivity than ice. Therefore, this layer reduces the rate at which heat is conducted to the still frozen interior. This insulating effect actually increases as the layer of thawed food grows. This is in contrast to freezing, where the increasing thickness of the ice layer causes heat transfer to accelerate. This is shown in Figure 7.5, where it can be seen that thawing is a substantially longer process than freezing when temperature differences and other conditions (size of package, etc.) are similar (Fellows, 1988). The thawing curve shows a rapid rise at the beginning when there is still no significant layer of

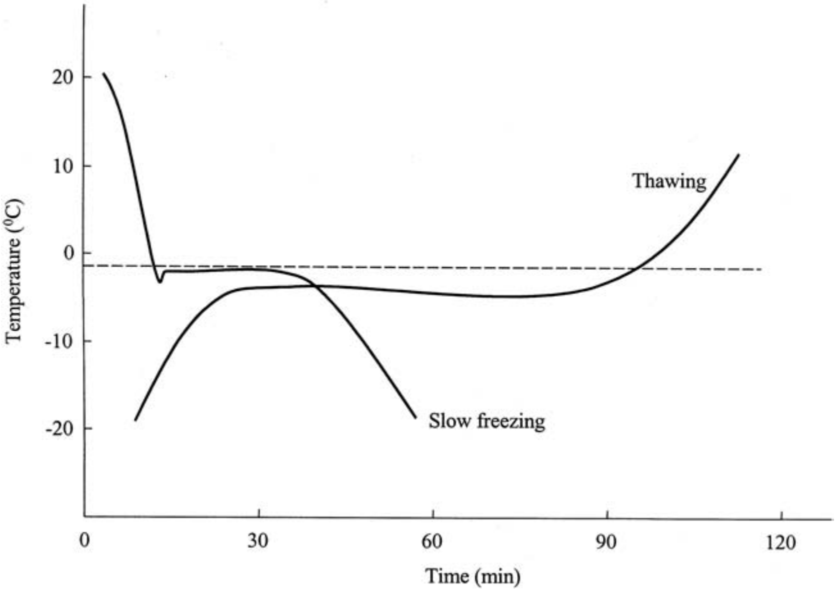


Figure 7.5. *Temperature Changes during Freezing and Thawing for Similar Size Packages. Adapted from Fennema and Powrie (1964).*

water around the food. Then, there is a long period (seen as a plateau) when the temperature is near the melting point.

Thawing can be done under different conditions where ambient temperatures should be cold enough not to encourage bacterial growth that could lead to food poisoning. The most common methods include the following:

- thawing in a refrigerator—which takes a few hours to a few days
- under running water—relatively fast
- in a microwave—very fast
- during cooking—very fast

Thawing at room temperature should be avoided at all costs in order to prevent extensive microbial growth.

The time required for thawing depends on factors such as the size of the meat cut/whole bird, initial temperature of the product and the thawing medium, thermal capacity of the meat and the thawing method.

PRESERVATION BY HIGH TEMPERATURE

Heat is used by the food industry and other industries (e.g., medical) to inactivate and/or kill microorganisms. The degree of microbial inactivation depends on the temperature and exposure time at a given temperature. Generally speaking, two levels of heat processing are used by the food industry:

- Pasteurization, which is moderate heating at about 60–90°C, designed to inactivate some of the spoilage and most of the food poisoning bacteria. The product's shelf life is extended, but the product must be refrigerated.
- Sterilization, where a temperature $>100°C$ is used to prepare the so-called "commercially sterile" food products that can be stored at room temperature for an extended period of time (e.g., canned food). This process results in killing all the spoilage microorganisms and destroying food poisoning bacteria and spores.

All heat treatments will result in changes to the product in terms of texture, flavor, odor and microbial load. The extent of changes increases with higher temperature and exposure time. The degree of microorganism destruction by heat is described in Chapter 11.

Cooking methods can vary from cooking the meat in its own juices, grilling and frying in oil. Heat can be transferred to the product in three different ways:

(*1*) *Conduction*—with this method, heat is conducted from an outside source and is directly transferred from one particle to the next with relatively no mixing and no movement of the product [Figure 7.6(a)]. This is usually true for solid, semisolid and viscous foods.

(*2*) *Convection*—this method involves heat transfer by mixing and moving particles in a fluid. Heated particles are less dense and rise to the top, whereas colder particles are more dense and move to the bottom. This is a more efficient heating method than conduction, because it results in the mixing of hot and cold particles through heat currents [Figure 7.6(b)]. Additional mixing during heating can be achieved by agitating, pumping or steering. The coldest point in the can is above the middle first third [Figure 7.6(b)], and that is where temperature should be monitored.

(*3*) *Radiation*—this is the transfer of heat energy through space, where a hot object gives up heat. For food applications, infrared lamps are usually used to emit energy that is absorbed by the product's surface.

Among the elements that affect heat transfer are the temperature differential between the heat source and the product, the length of heating applied and the medium involved. The composition of the meat, in terms of the moisture-to-fat ratio, also affects the heating rate. Thermal conductivity is the term used to express the rate of heat movement through a material. The other term is specific heat, which quantifies the amount of energy (heat) required to change the temperature of one gram of material by 1°C. Lean meat has more moisture and, thus, shows a higher specific heat compared to fat meat, meaning that it needs more energy to heat identical quantities.

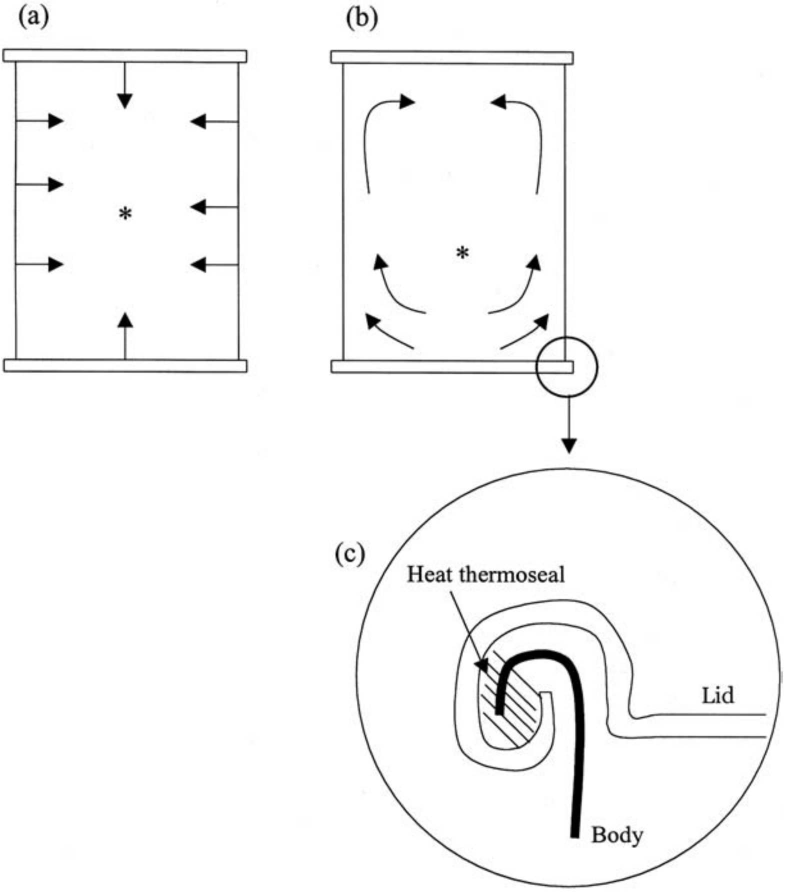


Figure 7.6. *Heat Transfer into a Solid Food Product, such as a Chicken Roll, by Conduction (a), and by Convection into a Liquid or Particulates in a Liquid such as Meat Chunks in Chicken Soup (b). The Notation "*" Shows the Coldest Point within the Can. Enlargement of the Double-Seam Closure of a Metal Can (c). Adapted from Fellows (1988).*

The heating of cut-up poultry parts, whole poultry and further processed products (e.g., sausages) can be done in regular ovens, convection ovens, microwave ovens, water (provided the product is properly packaged) and oil (frying). The different methods impart certain textures and flavors to the product, and choosing one method over another is usually based on factors such as the desired product identity, equipment available, operating costs and government regulations. The two main objectives of the cooking operation are to destroy food poisoning bacteria, as well as reduce the number of spoilage microorganisms, and to denaturate the proteins and thus form a firm texture. Part of the cooking operation can include a smoke application. This can be done in specially designed ovens that have a smoking application unit (e.g., generator of natural smoke, a spray system for liquid smoke); the effect of smoking on preservation will be discussed later in the chapter.

Retorting

The canning process, which is designed to achieve "commercial sterility," is commonly accomplished by using a retort, a large metal chamber capable of operating under pressure. The pressure is needed to obtain temperatures above 100°C. Usually, a temperature of 120°C or slightly higher is used in retorts, which helps reduce the required processing time to destroy heat-resistant microorganisms capable of forming spores. Poultry products that are processed in such a way include canned chicken soup, chunked chicken meat in gravy, turkey cubes with vegetables, etc. The product is usually packed in metal cans, glass jars or flexible retort pouches and can be stored at room temperature. In order to allow non-refrigerated storage, the product has to be processed at high temperatures and achieve "commercial sterilization" (for more information on the actual calculations, see Chapter 11). The rate of heat penetration into the product is very important. Figure 7.6 shows heat penetration patterns of two types of foods. For solid food such as chicken roll, heat transfer is by conduction, and for liquid or particulate food, such as meat pieces in a chicken soup, convection currents provide a faster heat transfer than solid foods. A factor that is important in determining the rate of heat transfer is the packaging material (stainless steel containers have a thermal conductivity of about 20 $Wm^{-1}K^{-1}$ compared to glass with a value of 0.52 and polyethylene with 0.55 $Wm^{-1}K^{-1}$; Fellows, 1988). Other factors include the size of the container, the temperature of the process (a higher temperature difference between the food and the heating medium results in faster heat penetration), the shape of the container and the agitation of the container.

The rate of heat penetration has to be measured so that the required residence time (within the retort) can be calculated. Thermocouples are placed in experimental cans at the slowest heating point. For conduction heating, this is the geometric center of the can and, for convection heating, it is approximately one-third up from the base (Figure 7.6); however, in convective heating, the exact position can vary and should be determined experimentally. The time-temperature calculations used to achieve commercial sterility (also known as the 12 D) are fairly complex and are beyond the scope of this book. For additional information, the reader is referred to textbooks such as that by Fellows (1988).

The high temperature retort treatment usually involves the use of saturated steam, under high pressure. This provides a temperature above boiling and, by that, shortens the processing time and causes less change to the food. Different types of retorts or sterilization chambers are available on the market. They basically consist of batch or continuous operations. In a batch-type operation, cans are placed in a large basket and lowered into a high-pressure chamber that is then closed, and the temperature is increased by injecting live steam [Figure 7.7(a)]. In a continuous retort, the cans continuously move through the operation where a hydrostatic head is produced in between two columns of water [Figure 7.7(b)]. This allows for closer control over the processing conditions and, hence, produces a more uniform product. The initial "leg" is used to gradually increase the temperature of the product before transferring it into the steam chamber. The last "leg" is used to initially cool the product that is then cooled by water sprays and possibly dipping in a cold water bath.

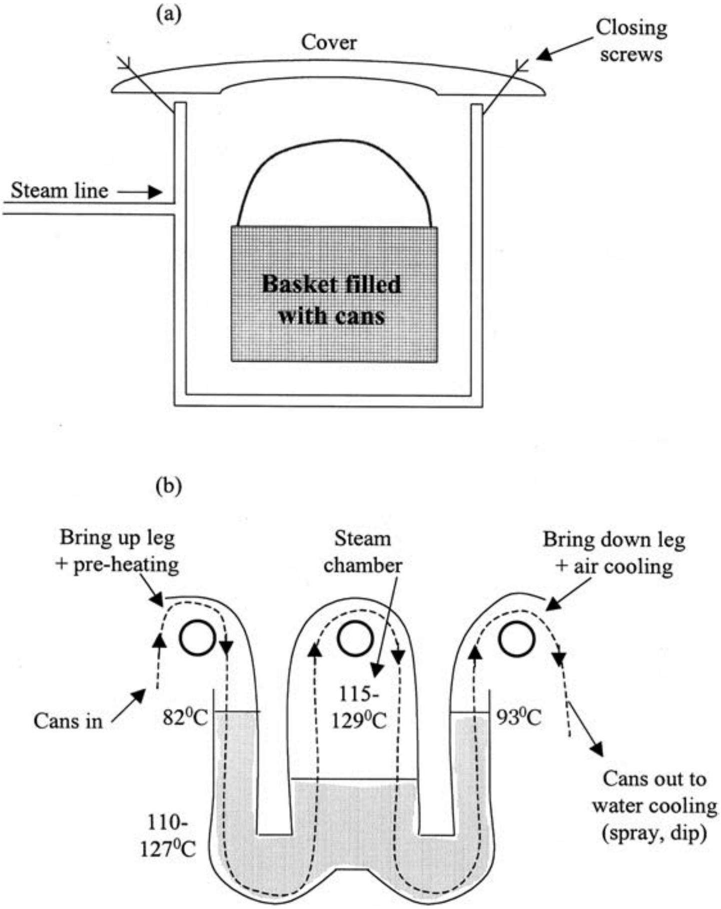


Figure 7.7. *Retorts used for a Canning Operation. A Batch-Type Sterilizer Employing a High Pressure Chamber (a), and a Continuous-Type Retort (b). Adapted from Fellows (1988).*

One of the most important things is to properly seal the can prior to the operation. The high temperature causes pressure to build up inside the can, and therefore, the seams should be able to withstand the pressure. Incorrect sealing or defects in the seam will cause leakage and suction of outside water or air that will recontaminate the food inside. The double seam construction of the conventional metal can is shown in Figure 7.6(c). This construction is achieved by using a seaming machine where the first operation is done by a roller that forms the cover hook around the body of the can. The second operation tightens the two hooks together to produce the double seam. A thermal plastic sealing compound is placed in between the can and the lid, and it melts during the heating process to fill the space and provide an additional barrier to contamination. Glass jars are covered with a metal lid that also has a thermal plastic sealing compound. Retort pouches are composed of various layers (e.g., aluminum foil, polyethylene), with one of the layers being a thermal plastic material or coating that becomes fluid when heated. A heat sealer warms the surfaces of the two sides of the film, and then pressure is applied to "fuse" the two sides together, which can result in significant problems for the manufacturer; during manufacturing, care should be to the integrity of the seam. Small defects can cause big problems if the product inside is recontaminated. From a consumer standpoint, it is important to remember that when in doubt (e.g., opening swelling cans, sensing off odor), the food should not be consumed.

Microwave Heating

This type of heating is based on inducing molecular friction within water molecules found in a food material (e.g., lean meat is 70% water). Water molecules consist of two hydrogen atoms attached to one oxygen atom. Because the angle between the two hydrogen atoms is 107°, the water molecule is negatively charged at the oxygen atom side and positively charged at the hydrogen atom side (i.e., forming an electric dipole). Microwave heating is attained by applying a rapidly oscillating electric field that causes reorientation of the water molecules. The realignment of water molecules causes friction that heats the product. There is a short delay of a fraction of a millisecond before the dipoles respond to the oscillating electrical field, called the relaxation time. The relaxation time is affected by the viscosity of the media and depends on temperature. When water changes to ice, the dielectric constant (i.e., the ratio of capacitance of the food to the capacitance of air or, in some cases, vacuum) falls and continues to decrease as the ice is further cooled. This means that ice is more "transparent" to microwave energy than water and this can cause problems when food is thawed in a microwave, as will be discussed below.

The microwave generator, called a magnetron, is a cylindrical diode. A ring of resonant cavities form the anode, and the cathode is a hot, metal cylinder that produces free electrons and is located inside the anode ring. When a high voltage is applied, the electrons give up energy to form rapidly oscillating microwave energy, which is directed to the waveguide by electromagnets. The food in the heating chamber may be rotating on a turntable, or a rotating antenna may be used to evenly distribute the energy (Fellows, 1988) in order to reduce "shadowing" (areas not exposed to radiation). The frequencies used in commercial microwaves are 2,450 MHz, and sometimes 915 MHz in the United States and 896 MHz in Europe. These frequencies are kept for microwave heating so no disturbance to radio waves, used for communication, will occur.

Because microwave heating is not dependent on the product's thickness, it is sometimes referred to as "heating from the inside," and it takes less time than relying on conduction in a convection oven. The rapid heating usually does not allow enough time for the development of browning on meat cuts cooked in a microwave oven. Therefore, some new residential ovens include microwave and convection ovens to speed up cooking and provide browning.

Microwave heating is also used for thawing meat, in homes and commercially, where large blocks of frozen meat can be thawed fairly quickly. However, as mentioned before, water has a higher dielectric constant compared to ice and, as a result, heats faster than ice. This can result in nonuniform heating, where some portions of the food may be cooked, while other portions remain frozen. To overcome this problem, the microwave power should be reduced, during thawing, to allow enough time for temperature equilibrium. Sometimes the meat industry uses microwaves only to defrost the meat (i.e., raising the temperature from −25° to −3°C). In this case, there is a limited phase change, and overheating does not present a major problem. The tempered meat blocks can then be easily sliced or boned. Using microwaves for defrosting is advantageous in reducing thawing time (e.g., minutes instead of days for large meat blocks), reducing drip loss and usually minimizing microbial growth, because very little time is allowed for microorganism recovery.

Packaging material should be transparent to microwave energy because materials such as metals reflect microwave energy and result in arcing as well as excessive heating of the packaging material. Therefore, various plastics, glass and paper with low dielectric loss are commonly used (Fellows, 1988).

Infrared Heating

This method of heating employs electromagnetic radiation emitted by hot objects and absorbed by the food. Infrared heat is less controlled and has a wider range of frequencies compared to microwave heating (Figure 7.8). In addition, the depth of penetration is lower, and heat transfer actually relies upon conduction from the surface to the interior of the food. The rate of heat transfer depends on factors such as the surface property of the food and the

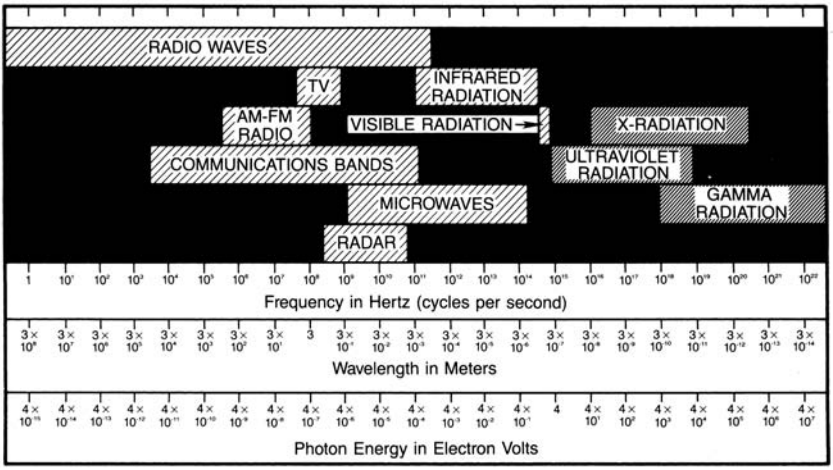


Figure 7.8. *The Frequencies, Wavelengths and Photon Energies of the Major Part of the Electromagnetic Spectrum. The Boundaries of the Named Segments are More or Less Arbitrary, and There Is Now Some Tendency to Reduce the Overlapping by Defining the Range Between TV and Infrared Radiation as Microwaves and the Range between Visible Radiation and X-Radiation as Ultraviolet. From CAST (1986). With Permission.*

temperature difference between the food and the heating lamp. Equipment used includes quartz or halogen tubes fitted with electric filaments, ceramic heaters or metal heaters. The temperature of the heating element can range from 900°C, for a quartz tube operating at medium wavelength, to 2,200°C for a heat lamp operating in the short wavelength range. Infrared radiation is mainly used to keep food hot in a display case. It is also used for drying non-meat products such as cocoa, pasta and flours, which are usually passed through a drying tunnel. The drying of cocoa, etc., is mentioned here because solar energy (indicated earlier as an old way of drying meat) consists of approximately 48% infrared energy.

Dielectric Heating

This heating method operates on a similar principal to microwave heating, but at lower frequencies. The food is passed between capacitor plates, where high frequency energy is applied to the food using an alternating electrostatic field. Changes in the orientation of dipoles are similar to those from exposure to microwave heating. However, in this case, the thickness of the food is restricted by the distances between the capacitor plates. The main usage of dielectric heating in the meat industry is for thawing blocks of frozen meat and sometimes cooking.

DRYING

Drying of relatively thin slices of meat over fire or under sunlight has been practiced since prehistoric times. The principle of this preservation method is based on reducing the water activity to a low level that will not support growth of microorganisms. Dried foods usually contain no more than 25% moisture and have a water activity of 0.00–0.60. Another category is the intermediate-moisture food that contains between 15–50% moisture with a water activity of 0.60–0.85 (Jay, 2000).

Today, poultry meat drying is done to preserve meat and also to obtain lightweight products. Such meats are used in dry soup mixes, dried foods for camping and food carried to space. The most economical way of drying is by using hot air, where small or thin slices are placed on trays and exposed to circulated dry air. Large meat chunks are usually not dried because surface hardening (i.e., fast water migration from the surface) can result in unacceptable products. Drying large pieces is also not economical because the process requires a very long time. During the drying process, attention should be given to the shape of the product, because it may shrivel and come out twisted or deformed. This is especially important for products such as turkey jerky, which is dried and later sold in flat packages. Another area of concern is fat oxidation that is accelerated during drying by hot air because of the large surface area exposed to oxygen. In order to overcome this problem, antioxidants should be added. The antioxidants can include synthetic antioxidants such as butylated hydroxy anisole (BHA) and butylated hydroxy toluene (BHT) or, where not permitted or desired, natural antioxidants such as rosemary oleoresin.

Freeze-drying is another way to remove the moisture from the product while maintaining its original shape. The frozen product is placed in a freeze-dryer chamber where vacuum is applied (usually 1–1.5 mm of mercury). The ice sublimates from the product without passing through the intermediate stage of liquid, and the process is called sublimation. In commercial freeze-dryers, rapid sublimation is achieved by applying a vacuum and raising the chamber temperature while the product is placed on a colder surface (cooled by a refrigeration coil). The product maintains its original shape because the water is sublimated while the product is frozen, and structural changes, such as shrinking, do not occur. Preserving the structure is desirable for meat particles to be used in products such as soup mixes where rehydration is faster compared to air-dried particles, and the textural characteristics of the rehydrated products are better. The moisture content in freeze-dried meat products is usually 2% or below. Thus, it is very important to properly package the product and exclude all moisture and oxygen from the environment. The dried product is susceptible to lipid oxidation because of the large surface area of the fat exposed to air. Rehydration of the product usually does not bring it back to its original moisture content. This can result in lower flavor notes, and usually, flavoring and seasonings are added to enhance the meaty flavor of the product. Cooking the meat prior to freeze-drying usually results in a more stable product compared to fresh meat. Several reports have indicated that the shelf life of cooked freeze-dried products is about 2–2.5 years (provided it is properly packaged), which is usually two to four times greater than the shelf life of freeze-dried fresh meat.

PRESERVATION BY CHEMICALS

Salt

Sodium chloride (NaCl) is one of the oldest ingredients used to preserve meat. Preservation is achieved by lowering the water activity, and hence, reducing water availability for microorganism growth. In addition, high salt concentration outside a bacteria cell can interfere with the cell metabolism, because the salt draws water from the cell. Salt concentration within the cell is around 0.90%. When the outside salt concentration is about the same, the cells experience a so-called *isotonic* condition, meaning that the salt concentrations inside and outside the cell are equal. When more salt is added to a suspension of microbial cells, the cells experience high exterior salt concentration. This results in water moving outside the cell in order to maintain an equilibrium. This in turn results in a condition known as *plasmolysis,* and this removal of water inhibits growth and can possibly kill the cell. In order to make a meat product shelf stable, a concentration of 10–15% salt should be used. This level is much higher than the 1.0–2.5% salt commonly used in most commercial further processed poultry products manufactured today (Barbut and Findlay, 1989). At 1.0–2.5% salt, other means of preservation, such as refrigeration, should be used to keep the product (e.g., poultry frankfurters with 2% salt left at room temperature will spoil within 1–2 days). It should be mentioned that some microorganisms are inhibited by a salt level of 2.0%, but the high water activity (around 0.98–0.99) is not sufficient to inhibit most bacteria, molds and yeasts (see Chapter 11). Another important point to remember is that salt is water soluble, and the calculation for salt concentration, used for preservation, should be done on the basis of the lean meat portion. For example, if 3% salt is added to a 30% fat turkey sausage, the actual salt concentration experience by bacteria in the lean phase is 4.2%.

Sugars

Sugars exert their preservative effect in basically the same manner as NaCl. One of the main differences is the relative concentration. It generally requires about six times more sucrose than NaCl to see the same inhibitory effect (Jay, 2000). Most meat products are not preserved by high concentration of sugars, but there are some specialty products in which a high sugar content is used. More commonly, sugar such as dextrose is added to fermented meat products as a substrate for the lactic acid bacteria growth and, thereby, indirectly assists in microbial inhibition. Dextrose concentrations of around 0.5–2% are commonly used and, by the end of the fermentation, most, if not all, of the dextrose has been converted to lactic acid.

Nitrite

Sodium nitrite ($NaNO_2$) and sodium nitrate ($NaNO_3$) are used in the curing process of different meat products. Nitrite's effects can be divided into three areas: (a) inhibit the growth of food poisoning organisms such as *Clostridium botulinum* and some other spoilage microorganisms, (b) stabilize the pink meat color by forming the nitrosohemochrome complex (see Chapter 13) and (c) contribute to flavor development, inhibition of oxidation and the formation of the so-called warmed-over flavor. The major reason for adding nitrite is to inhibit the growth of *C. botulinum* spores because most meat products are not cooked at above 100°C (i.e., spores usually survive boiling; see Chapter 11). The active compound in nitrite is nitric oxide (NO) that inhibits *C. botulinum* by interfering with iron/sulfur enzymes such as ferredoxin and, thus, preventing the syntheses of adenosine-triphosphate (ATP) from pyruvate. The chemical degradation of sodium nitrite within the meat system is described below:

$$NaNO_2 \rightarrow HNO_2 + Na + H_2O$$

$$3\ HNO_2 \rightarrow 2\ NO + H\ NO_3 + H_2O$$

If nitrate is used, it should be first reduced to nitrite by microorganisms present in the meat. The process takes more time and is preferred in fermented meat products where slow release of nitrite is required.

Nitrite levels used in processed meat products are very low and usually range from 100–150 parts per million (ppm). Levels are precisely regulated by government agencies to ensure that the levels prescribed are not exceeded because of the potential formation of nitrosamines, which are formed by the reaction of nitrite and secondary/tertiary amines under acidic conditions at high temperatures. Some of the nitrosamine compounds are known to be carcinogenic, so the levels of ingoing nitrite are closely monitored by inspection personnel. In meat products that are expected to be processed shortly after nitrite addition (e.g., frankfurters), reducing agents such as ascorbate and erythorbate are used at a level of about 500 ppm. Reducing agents such as ascorbate help to quickly convert nitrite into nitric oxide and reduce the chances of nitrosamine formation. In certain products that are expected to be exposed to high heat (e.g., turkey bacon which can be fried), lower levels of nitrite are prescribed.

To put things in perspective, one should be aware that meat products are not the major source of nitrite in our diet. Certain vegetables, such as celery, have nitrite levels in the range of 300 ppm. In addition, microorganisms present in the human gut produce quite a lot of nitrite within the body. During the cooking of sausages and other meat products, the level of nitrite is substantially reduced due to the conversion of nitrite to the nitric oxide gas. During storage, there is further reduction in the amount of measurable nitrite and, by the time the product is consumed, nitrite levels can be as low as 10–30 ppm. Over the past two to three decades, several suggestions have been made to eliminate or reduce nitrite levels in meat products (see additional discussion in Chapter 9); however, none have gained wide acceptance. One example for nitrite reduction was the addition of 0.25% potassium sorbate to about 40–80 ppm nitrite. This combination was found inhibitory to *C. botulinum,* but some flavor problems were reported. Another patented alternative was the use of 35 ppm encapsulated dinitrosyl ferrohemochrome as a coloring agent and 3,000 ppm sodium hypophosphate as an antimicrobial agent in a nitrite-free curing formulation for wieners (Yun et al., 1987). However, the process is not used on a large commercial scale.

Nitrite can also assist in preventing lipid oxidation and by that reducing the production of warmed-over flavors in precooked meat products, as well as stabilizing meat color (see Chapters 9 and 12, respectively).

Acids

Different organic acids are used to inhibit microorganism growth in meat products. The acids can be applied as sprays/rinses and marinades and can also be produced within the product during fermentation (e.g., lactic acid during summer sausage fermentation). Early application of acid rinses to poultry carcasses has been reported as a useful means of reducing microbial loads (see Figure 11.15 and discussion in Chapter 11).

Marinating cut-up chicken with ingredients such as lemon juice and vinegar is inhibitory to many microorganisms and helps in extending the shelf life. Marinated poultry parts (wings, thighs) are becoming very popular, and products are sold as convenience items requiring only grilling. The different acids used also add new flavors and aromas. Marination is not a new technique and has been used for centuries. The antimicrobial inhibition of organic acids is due to both the reduction in pH, below the growth range of microorganisms, and metabolic inhibition by the undissociated acid molecules. Overall, determining the inhibitory effect of a specific organic acid can be better measured by titratable acidity than by examining the pH alone. The latter is a measure of hydrogen ion concentration, and organic acids do not ionize completely. Titratable acidity measurements indicate the amount of acid that is capable of reacting with a known amount of base and is a better indicator of the amount of acidity present (Jay, 2000).

Phosphate

Different types of phosphate are used by the industry, and the most common one is the tripolyphosphate (TPP; see structure in Figure 9.2). Phosphates can alter the pH as well as emulsify fat (i.e., affect cell membrane) and cause a salt imbalance outside bacteria cells. Phosphate rinses and dips for poultry carcasses were suggested as early as 50 years ago. Due to their detergent activity resulting from their hydrophilic/hydrophobic structure, they have been tried as an antimicrobial agent for removing bacteria from poultry skin. In 1992, a commercial mixture of TPP and a few other ingredients was approved, in the United States, for poultry skin decontamination; high concentrations of about 10% are required. See Chapter 11 and Figure 11.5 for more information regarding the process.

Antibiotics and Bacteriocins

Antibiotics are compounds produced by microorganisms to inhibit or kill other competing microorganisms. Some of the most useful antibiotics in human medicine are produced by mold (e.g., *Penicillium*). Other antibiotic-like substances are produced by bacteria such as different *Bacillus* spp., and nisin is produced by a strain of *Lactococcus lactis*. Nisin is actually considered to be a bacteriocin and belongs to class I of the four major classes of bacteriocins. Like antibiotics, bacteriocins inhibit or kill other microorganisms, but only of closely related species or strains of the same species (Jay, 2000).

In early 1950, two antibiotics, tetracycline and subtilin, were approved for use in some food applications. They were later removed from the approved list in the United States and currently cannot be added to meat. Even though these antibiotics are very effective, there is a risk of developing strains resistant to tetracycline that might later be transferred to human beings. Because tetracycline is used as a therapeutic drug, it cannot be added to meat products. In general, antibiotics are not permitted in meat products.

Nisin has been used by the cheese industry to prevent spoilage of swiss cheese by *Clostridium butyricum*. Today, nisin is clearly the most widely used bacteriocin in food preservation and is permitted for use in around 50 countries. Some of its advantages include that it is naturally produced, heat stable and has an excellent storage stability, it can be destroyed by digestive enzymes in the body, it does not contribute to off-flavor or off-odors, it has a narrow spectrum of antimicrobial activity, it is not toxic to humans, and it is not employed in human medicine.

Smoke

Smoke has been used for centuries to preserve meat. The phenols, ketones, aldehydes and organic acids found in certain wood smoke have bacteriostatic and bactericidal effects and thus can inhibit or kill microorganisms. There are over 400 compounds that have been isolated from wood smoke, and they can be grouped into the four major groups indicated above. The phenols and organic acids contribute the most to the preservative effect of smoke. Today, smoked poultry products receive a light application to enhance the exterior color and to provide some special flavor notes (e.g., hickory, oak smoke flavorings). This means that the smoke is only deposited on the surface of the product and penetrates to a depth of 1–3 mm. This provides some bacteriostatic and bactericidal effects to the surface of the product but none to the bulk of the product. Cold smoking (i.e., smoking without cooking) is used to inhibit the growth of mold on uncooked, dry fermented sausages in countries such as Canada, where sorbic acid (mold inhibitor) spray is prohibited by government regulations. This is a very effective way of inhibiting mold growth on the surface of fermented products during the long drying process.

Sorbic Acid

Sorbic acid is used as a food preservative at a level of ≤0.2%, usually as a fungal inhibitor. Sorbic acid works best below pH 6 and is generally not effective above 6.5. As indicated before, sorbate can be used as a spray on fermented or nonfermented sausages to inhibit mold and yeast growth; however, sorbate is also effective against a wide range of bacteria. In general, catalase-positive cocci are more sensitive than catalase-negative bacteria, and aerobes are more sensitive than anaerobes. The resistance of lactic acid bacteria to sorbate allows it to be used as a fungistat in fermented meat products (Jay, 2000). As mentioned in the discussion regarding nitrite, a combination of sorbate and nitrite can be effective against *C. botulinum,* but it can cause some flavor problems described as “chemical” notes.

Spices and Flavoring Compounds

These are usually not used as antimicrobial agents per se, but some possess antimicrobial and antifungal characteristics. The antimicrobial activity is usually due to specific chemicals or essential oils found in a particular spice. These compounds are designed to fight microbial attacks in the living plant. Examples of some antibacterial compounds are as follows:

- cinnamon—cinnamic aldehyde and eugenol
- cloves—eugenol
- mustard—isothiocyanate
- oregano—carvacrol and thymol
- sage—thymol and eugenol (Shelef, 1983)

Some antioxidants that are mainly used to prevent lipid oxidation also possess some antibacterial activity. The phenolic structure of antioxidants such as BHA and BHT are inhibitory to Gram-positive and Gram-negative bacteria as well as to yeast and molds at concentrations ranging from 10–1,000 ppm, depending on the substrate. Foodborne pathogens such as *Salmonella, S. aureus* and *Bacillus cereus* are inhibited by concentrations of $>$500 ppm, while *Pseudomonas* is among the most resistant bacteria to BHA/BHT (Jay, 2000).

RADIATION

Using ionizing radiation to preserve food products is an acceptable method in some countries and is gaining acceptance in others. Ionizing radiation is defined as radiation with a wavelength of 2,000 angstrom (Å) or less (Figure 7.8). The radiations of primary interest to the food industry are gamma rays, beta rays, X-rays and alpha particles. Their quanta contain enough energy to ionize molecules in their path. Radiation, in general, is defined as the emission and propagation of energy through space or a material medium. Ionizing radiation used for food preservation destroys microorganisms without increasing the temperature of the media and, therefore, is also called "cold sterilization." The radiation sources used by the food industry include isotopic and machine-type radiation. The machine-type radiation is produced by an electron accelerator that generates a high-energy electron beam or high-energy X-rays for treating food. Isotopic irradiation is obtained by using isotopes such as Cobalt-60 (^{60}Co) or Cesium-137 (^{137}Cs) as a source of gamma rays. Cobalt-60 is produced in nuclear reactors by neutron-induced transmutation of naturally occurring ^{59}Co. Cesium-137 is a fusion product and is extracted from by-products of nuclear reactor fuel elements. The "strength" of an isotopic source is commonly expressed in terms of the rate of disintegration of radionucleid. The standard unit for activity is the curie, defined as 37 billion disintegrations per second. In addition to activity, the frequency of gamma ray emission should also be described. In the case of ^{137}Cs, gamma ray emission is in only 85% of its disintegrations, while ^{60}Co emits two gamma rays per disintegration. Another important characteristic is the isotopic half-life, which describes the length of time for the activity of the source to be halved as a result of decay. Cesium half-life is 30 years and cobalt half-life is 5.2 years.

Therefore, if not for other reasons, cesium would be chosen over cobalt (Faw and Chang-Mei, 1987).

Measuring the amount of radiation absorbed by the material (e.g., food) is described as the "dose." This can be roughly compared to the amount of heat (calories) a food product has absorbed while being placed in a hot oven. Measuring the amount of radiation absorbed is called dosimetry and is expressed as a unit called rad. A rad is a unit equivalent to the absorption of 100 ergs/g of matter. A kilorad (krad) is equal to 1,000 rads, and a megarad (Mrad) is equal to one million rads. A newer unit of an absorbed dose is the gray (1 G = 100 rads = 11 joule/kg; 1 kGy = 10^5 rads).

The radiation dose used for different applications is shown in Figure 7.9. Similar to heat processing, small amounts of radiation will result in pasteurization (i.e., killing some spoilage and pathogenic microorganisms), whereas a high dose will result in the so-called "commercial sterilization."

The latter is called radappertization and can achieve similar results to a heat-treated canned food. Usually, the levels are about 30–40 kGy.

Radicidation is similar to pasteurization of a product such as milk and is designed to reduce non-spore-forming pathogens, other than viruses. The typical levels are 2.5–10 kGy.

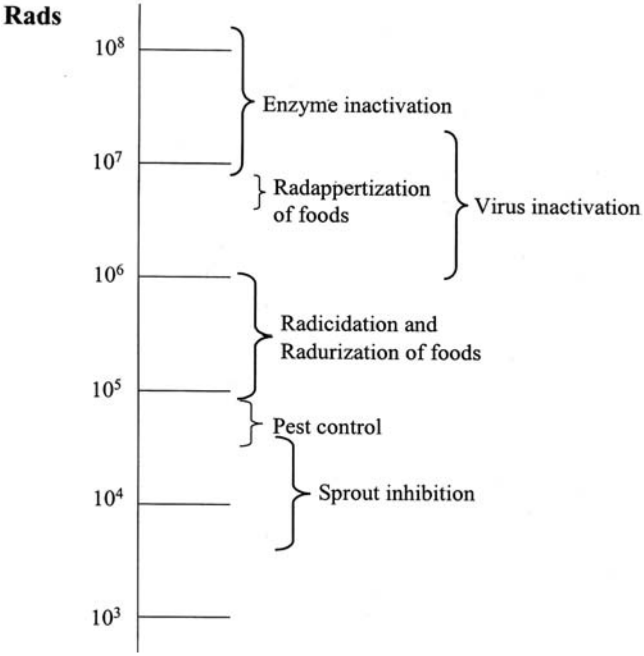


Figure 7.9. *Dose Ranges of Irradiation for Various Applications. Adapted from Grunewald (1961).*

Radurization is a lower level pasteurization that is used to reduce specific spoilage microorganisms with a common dose level of 0.75–2.5 kGy. This is also used for fresh poultry, seafood, fruits and vegetables to enhance shelf life.

Similar to heat inactivation of microorganisms (described in Chapter 11), there are *D*-values assigned to radiation treatments for different microorganisms. These values are useful in designing radiation treatments for different foods. Table 7.1 shows some average *D*-values. Similar to heat treatments, spores are more resistant to radiation as compared to non-spore-forming microorganisms. There are also differences in the spore resistance of similar types within the same microorganism (*C. botulinum* type E vs. type B; see Table 7.1). Once the toxin has been formed, a very high dose is required to inactivate the toxin (36 kGy). The same can be seen for the *S. aureus,* where the *D*-value for the live bacteria is 0.16 kGy, and for the toxin, it is about 61 kGy. This is an interesting difference from heat processing where the *C. botulinum* toxin is a fairly heat-sensitive compound (can be inactivated by boiling for a few minutes) as opposed to the spores that require boiling for a few hours. The reason is that the toxin is a small peptide that can be denatured and inactivated fairly easily by heat but not by radiation. Viruses are more resistant to irradiation compared to bacteria as can be seen in the case of the adenovirus (Table 7.1).

It is important to obtain actual dosimetry values in order to ensure that the product was exposed to the desired level, and that the required pasteurization/

Table 7.1. Overview of Average Radiation *D*-Values for a Variety of Foods. Adapted from a Summary by Jay (2000).

Organisms/Substance	*D*(kGy)
Bacteria	
Clostridium botulinum, type E Beluga	0.8
C. botulinum, type 62A spores	1.0
C. botulinum, type B spores	2.38
C. botulinum A toxin in meat slurry	36.08
Escherichia coli	0.20
Listeria monocytogenes	0.42–0.43
on meat at 5°C	0.44
on meat at 0°C	0.45
on meat at −20°C	1.21
Pseudomonas putida	0.08
Salmonella typhimurium	0.50
S. enteritidis in poultry meat at 22°C	0.37
Staphylococcus aureus	0.16
toxin A in meat slurry	61.18
Yersinia enterocolitica, in meat	0.19–0.38
Viruses	
Adenovirus (four strains)	4.1–4.9

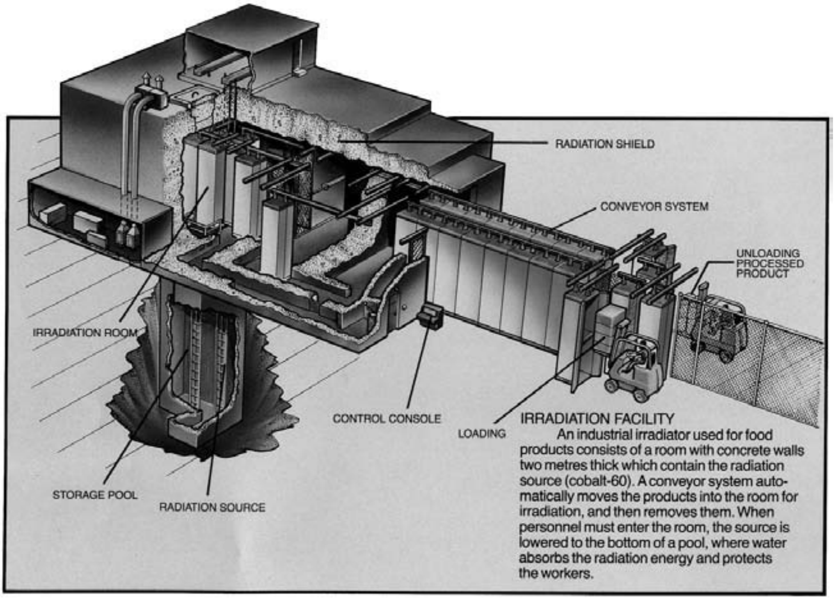
sterilization level was achieved. Two main dosimetry systems are commonly used. The first is based on colorimetry and is suitable for short irradiation periods. The second is based on ceric sulfate where ceric ions, in acidic aquisolution, are reduced by the action of ionizing radiation to cerous ions. The change in ceric ions can be readily measured by spectrophotometric method. Secondary dosimetry systems are also used and are usually calibrated against one of the primary dosimetry methods mentioned above. One such secondary system involves darkening of polymethyl methacrylate exposed to irradiation. Later, the relative darkening is measured by a spectrophotometer.

Figure 7.8 shows the frequencies, wavelengths and photon energies of the major part of the electromagnetic spectrum. As can be seen, the shorter the wavelength, the greater the energy it carries (electromagnetic radiation occurs in units called quota or photons). When the quantity of energy in a quantum exceeds the energy that binds adjacent atoms in a molecule, the molecule can break, and the chemical bond can be cleaved off, resulting in smaller fragments that may be electrically charged (ions) or neutral. Ultraviolet, X-rays and gamma rays are capable of breaking fairly stable bonds and even expelling electrons from atoms. Therefore, they are known as ionizing radiation or ionizing energy. Visible light, for example, has such a tendency, but to a much smaller degree, and it can only break weak bonds (CAST, 1986).

The depth to which visible light can penetrate in most solids is in the order of 1 micron. Gamma rays and X-rays can penetrate much deeper. Those with energy of 0.15 to 4 million electron volts (eMv) can penetrate about 30 cm of water. Fast-charged particles such as electrons, alpha particles and protons also have enough energy to cleave molecules as they penetrate the material. Accelerated electron guns with an energy of 10 million eMv can penetrate to a depth of about 4 cm. However, accelerated alpha particles and protons do not have enough penetrating power to be of practical use in food applications.

Currently, there are two types of commercial food irradiation facilities on the market. The first uses a radioactive isotope (Figure 7.10), and the second employs an electron beam accelerator (Figure 7.11).

Once the food has been treated, it has to be labeled (see symbol, Figure 7.12) to indicate that the food has been exposed to radiation, letting the consumer decide if he/she wants to purchase the product. Commercial irradiation of fresh poultry, beef and pork meat was approved in 1999 in the United States. In other countries such as the Netherlands, food irradiation was approved many years ago; while in other countries such as Canada, permits for experimental trials of poultry have been granted. Overall, food irradiation is becoming more acceptable today in different parts of the world. Among the reasons are the *E. coli* 0157:H7 problems in beef (see Chapter 11) and attempts to market *Salmonella*- and *Campylobacter*-free poultry meat. As mentioned before, irradiation provides a "cold sterilization" process that does not change the physical state of the food. In the past, some people in the food in-



IRRADIATION FACILITY

An industrial irradiator used for food products consists of a room with concrete walls two metres thick which contain the radiation source (cobalt-60). A conveyor system automatically moves the products into the room for irradiation, and then removes them. When personnel must enter the room, the source is lowered to the bottom of a pool, where water absorbs the radiation energy and protects the workers.

Figure 7.10. *An Industrial Irradiator Used for Food Products, Consisting of a Room with Concrete Walls that Contains the Radiation Source (Cobalt-60), and a Conveyor System Used to Move the Products into the Room. Courtesy of MDS Nordion Inc., Kanata, ON, Canada.*

dustry have argued that labeling should not be mandatory because irradiation is just a process applied to the food, and other processes, such as heating, freezing and drying, do not require special labeling. However, most governments and international bodies have agreed that food irradiation should be considered differently, and a label, or a logo, should appear on the package. In order to alleviate consumer fear, the word picowave has been suggested to replace the word irradiation. This is based on the range of wavelength used for irradiation (picowave = 1 trillionth of a meter on the electromagnetic spectrum). This was suggested based on similar use of the word microwave (micro indicates 1 millionth of a meter on the electromagnetic spectrum). The term picowave was first suggested in the early 1980s, however, it has not gained wide acceptance.

In terms of food safety, the World Health Organization concluded in 1981 that “no hazard is involved in processing any food with ionizing energy up to an average dose of 10 kGy; hence, toxicological testing of food so treated is no longer required” (WHO, 1981). The WHO conclusion was based on the following three factors:

(*1*) All the toxicological studies carried out on a large number of individual foods have produced no evidence of adverse effects as a result of radiation.

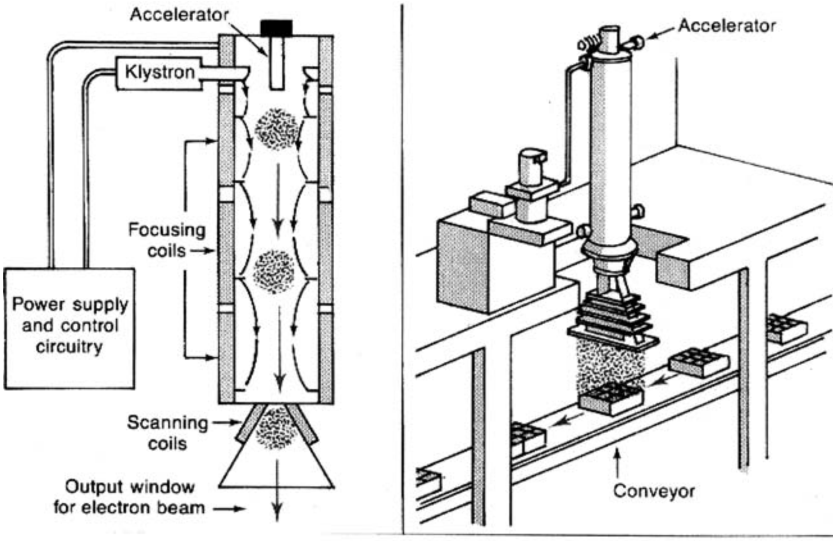


Figure 7.11. *A Diagram of a Typical E-Beam Accelerator Used for Food Irradiation. Courtesy of The Electrical Power Research Institute, Palo Alto, CA, U.S.A.*

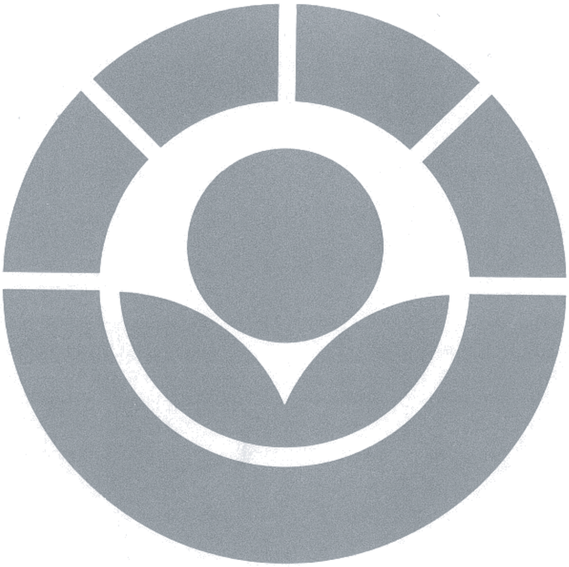


Figure 7.12. *The International Symbol for Food Irradiation.*

(*2*) Radiation chemistry studies have shown that the radiolytic products of major food components are identical, regardless of the food from which they are derived. Moreover, for major food components, most of these radiolytic products have also been identified in foods subjected to other acceptable types of food processing. Knowledge of the nature and concentration of these radiolytic products indicates that there is no evidence of a toxicological hazard.

(*3*) Supporting evidence is provided by the absence of any adverse effects resulting from the fitting of irradiated diets to laboratory animals, the use of irradiated feeds in livestock production and the practice of maintaining immunologically incompetent patients on irradiated diets.

The WHO conclusion and recommendation was further elaborated into an international standard under the procedure of the Codex Alimentarius Commission, and in 1983, it was adopted by 130 governments. The standard has provided an important incentive for national authorities to introduce favorable regulations for food irradiation. Thayer (1994) reviewed the wholesomeness of irradiated food, (including data cited by the Food and Drug Administration) in support of approving irradiated poultry meat, at 1.5–3.0 kGy), to control foodborne pathogens for commercial sale in the United States. Thayer concluded that neither short nor multigenerational feeding studies have produced evidence of toxicological effects in mammals due to ingestion of irradiated food. This supported the conclusion that properly processed irradiated food is wholesome, and that radiolytic changes in the food are minimal and predictable.

Using irradiation to treat poultry meat at the radurization and radicidation levels can assist in reducing foodborne diseases caused by bacteria such as *Salmonella, S. aureus* and spoilage microorganisms such as *Pseudomonas* and *Lactobacilli*. The effect of radiation dose on spoilage microorganisms on freshly slaughtered chickens stored at 2°C is presented in Table 7.2. Niemand et al. (1977) have shown that nonirradiated control was spoiled within 4–6 days. This is about the normal shelf life of eviscerated poultry (for more

Table 7.2. Effects of Irradiation Dose on Total Plate Counts (per cm^2) of Chicken Carcasses Stored at 2°C. Adapted from Niemand et al. (1977).

Days Stored	Irradiation Dose (kGy)				
	Control	2	3	4	5
1	0.2×10^5	$<10^2$	~50	<10	<10
6	1.2×10^8	1.7×10^4	~50	<10	<10
12	—	4.5×10^6	3×10^3	1×10^2	<10
20	—	—	5×10^6	2×10^5	5×10^3

information, see Chapter 11; poultry meat spoiling when reaching 10^7–10^8 bacteria/cm^2). A major improvement was achieved by using an irradiation dose of 2–5 kGy. The reduction was in the range of 3–4 logs, and the shelf life more than doubled. Using 5 kGy resulted in more than tripling the shelf life. The results are in agreement with experiments conducted prior to and after 1977. Others have shown that irradiating eviscerated poultry with 2.5 kGy resulted in an essentially *Salmonella*-free product. In a study involving artificially contaminated broiler skins, Mulder (1982) reported a range of *D*-values for irradiation at above and below the freezing point (Table 7.3). The values are in agreement with *D*-values obtained for *E. coli* and *Salmonella* reported for other foods (Table 7.1), where irradiating at −18°C provides more protection to the microorganisms and, thus, requires higher doses to achieve the same level of inactivation. Mulder also indicated that the application of 2.5 kGy to Dutch poultry could not guarantee a *Salmonella*-free product but would reduce the number of *Salmonella*-positive poultry by a factor of 14. It should be mentioned that today the situation is different in the Netherlands, where a major effort to eradicate *Salmonella* (i.e., farm-to-plate approach) has been employed by the industry within the last decade (see Chapter 11).

Exposure of meat to medium or high levels of irradiation can result in the formation of off-flavors and odor. This is mainly the result of lipid oxidation that can be accelerated by irradiation. Therefore, it is generally recommended that meat irradiated at medium to high levels be vacuum packed, especially when a high dose (20–70 kGy) is applied; a subfreezing temperature is also recommended to minimize off-flavor formation. High-level radappertization is used to achieve "commercial sterility" equivalent to thermal processing of canned food. The product can then be stored at room temperature without spoilage. For radappertization, a mild heat treatment, at about 70–77°C, is usually applied in order to inactivate proteolytic and lipolytic enzymes. This inactivation can minimize deterioration of flavor, odor and texture during storage, because not all enzymes will be inactivated by the radiation treatment (Josephson, 1983). Although enzyme inactivation, by heat, results in some textural changes and moisture loss, it is necessary for the long-term quality

Table 7.3. D-Values (kGy) of Salmonellae and *E. coli* on Artificially Contaminated Broiler Carcasses. Adapted from Mulder (1982).

	Irradiation Temperature	
Organism	+5°C	−18°C
Salmonella niloese	0.54–0.68	0.88–1.25
Salmonella panama	0.67	1.25–1.32
E. coli (K12 NDA)	0.27–0.44	0.72

preservation of the product. Adding salt and phosphate to the meat can reduce moisture losses (see Chapter 9). The meat can be packaged in metal cans, glass jars or flexible pouches. If a high irradiation dose is applied, freezing (e.g., −20 to −40°C) is recommended to reduce deterioration due to oxidation (Josephson, 1983). As mentioned earlier, the *D*-value of microorganisms irradiated at the frozen state is much higher than *D*-values obtained at above-freezing temperatures (Tables 7.1 and 7.3), and, therefore, a higher dose is required to achieve sterility at subfreezing temperatures. As with heat-processed cans, *C. botulinum* spores are the main target and, because they are fairly radiation-resistant organisms (Table 7.1), a relatively high dose should be used. To assure complete sterilization, the 12-D concept is also used here (for more information on the 12-D concept, see Chapter 11). Anellis et al. (1977) have determined the required 12-D dose for chicken meat with NaCl (0.75%) and tripolyphosphate (0.3%) to be 42.7 kGy when radappertized at −30°C after enzyme inactivation at 74°C. Even though the sensitivity of *C. botulinum* is the highest at 0°C, the product (2,000 cans of inoculated chicken meat) was treated at −30°C to minimize flavor deterioration at this relatively high dose.

In a study involving frankfurters inoculated with five strains of *C. botulinum* at a level of 10^3 spores/g, Barbut et al. (1988) showed that a higher salt level provided better protection from toxin production under abused temperature conditions. They showed that radiation exposure of 5 kGy or greater, at either 1° or −30°C, was sufficient to inhibit botulinum toxin production for 40 days in temperature-abused (25°C) turkey frankfurters containing 2.5% NaCl or greater. Neither 5 nor 10 kGy inhibited toxin production in products formulated with 1.5% NaCl.

Energy Consumption and Costs

The relative energy usage for low- and high-dose irradiation are provided in Table 7.4. Overall, the energy required for preserving/extending the shelf life of food by irradiation is relatively low compared to refrigeration and freezing. This means that radurization of fresh chicken only adds marginally to energy usage, while offering considerable advantages through reduced spoilage, extended shelf life, reduction of *Salmonella* hazard and, overall, more flexibility in distribution. However, it should be pointed out that the costs to irradiate the product are not proportional to the energy usage only because of the high capital costs for constructing an irradiation facility or the transportation costs to an existing facility. Daily operational costs of an irradiation facility can also be significant, and therefore, the facility is designed to operate 24 hour a day (sometimes sharing with other food items, medical equipment, etc.). The goal is to make the system more efficient and reduce overhead cost per unit. The overall cost to irradiate 1 kg of product depends on many factors and can vary greatly around the world. Therefore, local manufacturers/

Table 7.4. Energy Usage for Food Preservation and Total Energy Usage in a Poultry Processing Operation. Data from Brynjolfsson (1978).

Energy in Food Processing (kJ/kg)	
Low-dose radiation pasteurization (2.5 kGy)	21
High-dose radiation sterilization (30 kGy)	157
Thermal sterilization (retorting)	918
Blast freezing (4.4°C to −23.3°C)	7,552
Refrigeration at −25°C for 3.5 weeks	5,149
Refrigeration at 0°C for 5.5 days	318
Cooking whole, thawed chicken	2,558
Total Energy Usage from Poultry Slaughter through Preparation (kJ/kg of Edible Portions)	
Refrigerated, raw, cut-up chicken	17,760
Refrigerated and radiation-pasteurization, raw, cut-up chicken	17,860
Frozen, raw, cut-up chicken	46,600
Frozen, cooked long chicken rolls	27,550
Retorted, canned chicken meat	20,180
Radiation-sterilized, cooked long chicken rolls	14,260
Radiation-sterilized, cooked individual servings	15,460

distributors of irradiation facilities should be consulted before a decision is made about using this means of preservation. Another crucial factor is consumer acceptance. Commercial food irradiation technology was developed after World War II and has been available for the past half century. It is currently used to treat a large portion of our medical supplies (e.g., bandages, tubes that are sensitive to heat), spices and various foods around the world. However, consumer acceptance of irradiated food products has been one of the main stumbling blocks in North America over the past few decades. As mentioned earlier, this attitude is slowly changing due to various foodborne disease outbreaks (e.g., *E. coli* O157 in beef hamburger meat), and it appears that food irradiation will become more widely used in the future.

MODIFIED ATMOSPHERE AND VACUUM PACKAGING

Modified atmosphere is the process of altering the normal mixture of atmospheric gases [i.e., roughly 79% nitrogen (N_2), 20% oxygen (O_2) and 0.03% carbon dioxide (CO_2)] into an atmosphere that will discourage the growth of certain microorganisms. The process involves either the evacuation of all the air from the bag (vacuum packaging) or artificially increasing the concentration of one or two gases; a process referred to as controlled atmosphere or modified atmosphere (MA) packaging. MA storage of plant material has been used since the early 1920s, where fruits, such as apples and pears, were stored in elevated CO_2 environments. This was done to retard fungal rotting of the fruits. During the 1930s, meat was shipped from Australia and New Zealand to England in containers enriched with CO_2 in order to extend the shelf life of the meat. This has been a very successful development for the red meat industry, because shelf life of unfrozen meat could be extended to 3–4 months (Jay, 2000). In his review, Genigeorgis (1985) showed numerous publications supporting the findings that high CO_2 concentration increases the shelf life of a variety of meats. It is important to note that the packaging material should be of high quality and should maintain the prescribed conditions (e.g., a poor oxygen barrier film will not function as intended).

Various gas mixtures have been suggested as a means of increasing the shelf life of packaged meat. They range from 0–100% CO_2 with or without the inclusion of nitrogen and/or oxygen. In vacuum-packaged meat (considered part of MA packaging), the amount of CO_2 that can be accumulated during a week of refrigerated storage is around 30%. The increase in CO_2 is the result of the residual oxygen consumed by microorganisms and their resulting respiratory activity (Jay, 2000). MA conditions can be achieved in several ways:

- evacuating the air from the meat bag with a vacuum pump (pressure of 10–750 mm Hg are used)
- removing the air by squeezing or placing the lower part of the bag in water to physically remove the air
- flushing the product with a gas mixture of choice by special equipment

There are quite a few similarities between vacuum-packed and gas-flushed meats, because the primary inhibitory effect is caused by CO_2 (i.e., CO_2 concentrations in vacuum-packed meat increase over time due to microbial respiratory activity). Overall, Gram-negative bacteria are more sensitive to CO_2 than Gram-positive (see Chapter 11), with *Pseudomonas* being among the most sensitive and lactic acid bacteria and anaerobes being among the most resistant. The main differences between the microflora of fresh and vacuum-packed meat are the dominancy of Gram-positive bacteria and fewer yeasts in the vacuum-packaged meats (Jay, 2000). Two main mechanisms have been offered to explain the inhibitory effect of CO_2. The first suggests that CO_2 affects the permeability of the lipid bilayer in the cell membrane and increases its fluidity (Enfors and Molin, 1978). Enfors and Molin showed that at 1 atm CO_2, germination of *B. cereus* spores was inhibited. The same was reported for *P. fluorescens*. The second mechanism suggests that CO_2 can block the metabolism of the enzymatic decarbonization system in bacteria such as *Pseudomonas aeruginoxa*. Enfors and Molin (1978) and others have also shown that CO_2 inhibition increases as temperature is reduced. Jay (2000) indicated that although CO_2 has been known, for the past century, to inhibit certain microorganism groups, there is still no clear understanding of how inhibition is achieved. From a practical standpoint, the fact that the inhibitory affect of CO_2 increases with decreasing temperature can be used to enhance the shelf life of further processed poultry products such as chicken nuggets (Marshall et al., 1992). These authors have shown that the competitive growth of *Listeria monocytogenese* and *Pseudomonas fluorescens* on precooked, dark meat chicken nuggets was enhanced using modified atmosphere (80% CO_2, 20% N_2) while storing at 4°C. In fresh chicken quarters, the shelf life was extended to 35 days at 2°C when packaged under 60–80% CO_2 (Hotchkiss et al., 1985).

Various reports have clearly shown that when vacuum-packaged meats spoil, the predominant organisms are lactobacilli and/or *B. thermosphacta*. Other organisms can be found and sometimes dominate the microflora. Among the determining factors influencing the microflora are whether the product has been cooked, relative load of psychotrophic bacteria, the degree to which oxygen was excluded, the product's pH and nitrite concentration (Jay, 2000).

Most sliced poultry meat products (e.g., salami, bologna, frankfurters) are packaged under vacuum to minimize oxidation and increase the shelf life. In a study on the microflora of cooked bologna-type sausage, Neilson and Zeuthen (1985) showed that vacuum packaging resulted in the normal flora restricting *Yersinia enterocolitica* and *Salmonella* but not *S. aureus*. The normal microflora actually inhibited *C. perfringens,* and all pathogens were inhibited by the lactic acid bacteria, with greater inhibition when storage temperature was lowered.

The spoilage of vacuum-packaged meat products and the production of off-odors and off-flavors is usually the result of metabolites produced by microorganisms. Long-chain fatty acids cleaved into short chains are the byproducts of *Lactobacilli* and *B. thermosphacta* activity and result in offensive off-odors. Acetone and diacetyl have been reported to be the most significant compounds responsible for the off-odor of vacuum-packaged luncheon meat.

In fresh vacuum-packaged products, the production of sulfide odors can be the result of *Pseudomonas* and *Hafnia alvei* activity. The sulfide smell is usually evident when the number of microorganisms reaches 10^7–10^8/cm^2, which commonly indicates extensive proteolysis by microorganisms using amino acids as an energy source. Slime formation can also be evident as will be discussed below. Freeman et al. (1976) studied the volatiles produced by bacteria causing spoilage of fresh and irradiated chicken. They identified dimethyl disulfide, methyl mercaptan, H_2S, methanol and ethanol as the main compounds.

Spoilage of further processed, cooked poultry products can result from high microbial loads on the fresh meat, spices and casings (more frequent with natural casings). If inappropriate production procedures (e.g., warm temperature) are used, the shelf life may be significantly shortened. Some of the most common problems associated with microbial degradation include the following:

- *Off-odors* are exhibited as offensive smells. Examples of bacteria that can contribute to putrid off-odors include *Pseudomonas* and lactic acid bacteria (see previous paragraph).
- *Slimy appearance* can be seen on the surface of the product and is the result of microorganisms capable of producing slime to protect themselves (see Chapter 11). Among the microorganisms that can be isolated in this case are the lactic acid bacteria of the genera *Lactobacillus, Enterococcus, Weissella* and *B. thermosphacta*. Slime formation is favored by moist surfaces and is usually confined to outer casings (Hedrick et al., 1994). Therefore, processors of cooked products are adding ingredients, such as whey proteins, that can bind the moisture and prevent exudate in the package. This is especially important in vacuum-packaged goods, where there is a physical force drawing moisture out of the product.
- *Greening* is usually caused by H_2O_2 and H_2S production in fresh and cooked products. In cooked products, both chemicals can interact with the nitrosohemochrome and oxidize the porphyrin rings. By doing so, the color is changed from red to green (see Chapter 13 for color reactions). The greening can appear as a green core, on the surface or throughout the product. A green core can appear after an aerobically stored product is sliced and exposed to air. It usually indicates inappropriate cooking temperature, where the desired internal temperature has not been achieved, and microorganisms capable of producing H_2O_2 or H_2S have survived. An outer green ring usually indicates high contamination levels of the fresh meat surface or the casings. Some of the most common microorganisms known to cause H_2O_2 production in processed meats are *Weissella viridescens* (most common), *Leuconostoc, Enterococcus faecium* and *Enterococcus faecalis*.

  Greening of vacuum-packed, fresh meat stored at refrigerated temperatures is usually caused by H_2S production, where the H_2S reacts with myoglobin to form sulfmyoglobin. The main microorganism responsible for this is *Pseudomonas mephitica*. The H_2S is usually formed by the degradation of the cystine amino acid, which contains sulfur. The green color usually appears when the microorganisms reach $10^7/\text{cm}^2$ (Jay, 2000).

  It should be mentioned that internal green patches in freshly slaughtered turkey meat have also been reported. However, in this case, the problem is attributed to deep-muscle-myopathy caused by the death of muscle fibers at these regions and is not related to bacterial spoilage. The problem is associated with the fast growth of the breast muscle in the modern turkey and the inadequate development of blood supply (see additional discussion in Chapter 9).

- *Yellowing* is a discoloration that has been seen in sliced white poultry meat products contaminated with *Enterococcus casseliflavus*. This type of discoloration starts as small yellow spots on products stored under refrigeration, and it usually appears after 3 to 4 week of storage. The organism can survive a heat treatment of 71°C for 20 minutes, but not for 30 minutes, indicating that inappropriate cooking might be a problem. Overall, it is a fairly rare problem, but it is usually hard to trace the exact contamination/cross-contamination source because it appears after a prolonged storage period (Whitely and D'Sousa, 1989).
- *Souring* can occur in stored, cooked meats due to the growth of *Lactobacilli, B. thermosphacta* or *Enterococci,* which are capable of fermenting different sugars (usually added to the product as milk ingredients or dextrose). The microorganisms use the carbohydrates as an energy source and convert them into acids that cause souring. Overall, processed meat products commonly contain a fairly varied microflora because of the different meat sources, spices and other non-meat ingredients used. Therefore, if adequate sanitation, quality control, cooking and cooling procedures are not employed, a variety of problems may arise.
- *Gas production* in vacuum-packaged sliced meats is usually the result of bacteria from the *Clostridium* family growing in the product. The meat is then unfit for human consumption. The main gas is CO_2, a water- and lipid-soluble gas that has some bacteriostatic effect. In a packaged meat system, the following chemical reactions can occur:

$$CO_2 + H_2O \leftrightarrows H_2CO_3 \leftrightarrows HCO_3^- + H^+$$

The proportion of the carbonic acid produced in stored meat can be related to temperature conditions, pH, etc.

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CHAPTER 8

Meat Processing—Equipment

INTRODUCTION

DIFFERENT pieces of equipment are used in the fabrication of raw meat into further processed meat products. In the past, equipment was designed for a manual and/or batch-type operation; however, today many processing lines are designed to accommodate continuous operation. This speeds up manufacturing, allows more volume to go through a given plant, permits more centralized control and, as a result, saves on operation costs. The various basic steps involved in sausage processing are illustrated in Figure 8.1. Depending on the product being made, some or most of the steps will be employed. For whole muscle products (e.g., oven roasted turkey breast), grinding/chopping is not included, and non-meat ingredients (e.g., salt, water, spices) are commonly added by injection, as will be described later in the chapter. It should be mentioned that all processes performed prior to cooking should be carried out at a refrigerated temperature (e.g., in the United States the FSIS requires $<10°C$) in order to minimize microbial growth (see Chapter 11). Good sanitation practices and an adequate HACCP program can further assist in the production of safe products (see Chapter 12; also includes detailed flow diagrams of equipment and specific steps involved in the production of cooked turkey ham, and battered and breaded chicken; Figures 12.2 and 12.3, respectively). In this section, the basic types of equipment used in meat processing plants and their operational principles will be described. It should be remembered that many variations exist in terms of equipment design, size and configuration, but most operate under fairly similar basic principles.

SIZE REDUCTION

Size reduction of large meat chunks is the most common process involved in the manufacturing of ground and comminuted meat products (e.g., breakfast sausage, salami and frankfurters). The three main methods used are grinding, flaking and chopping.

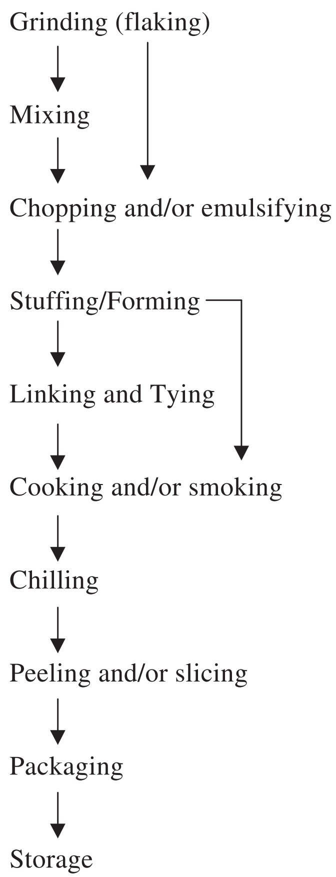

Figure 8.1. *Basic Steps Involved in Sausage Processing.*

Grinding

This is probably the most common method of reducing meat particle size. In this process, meat is forced through a grinding plate that can have different size openings. An auger is used to convey the energy (manual or electric) to push the meat through a moving set of blades and a grinding plate [Figure 8.2(a)]. The size of the equipment can vary depending on volume required and ranges from small manual grinders that can process a few kg/hr to large grinders capable of processing thousands of kg/hr. In order to minimize heat buildup, especially at the pressure building area of the head, the blades should be kept sharp, and the plate should be in good shape (e.g., not worn out). In addition, the auger should precisely fit into the barrel. When the operator notices an uneven pattern of the meat coming out from the grinder, the machine

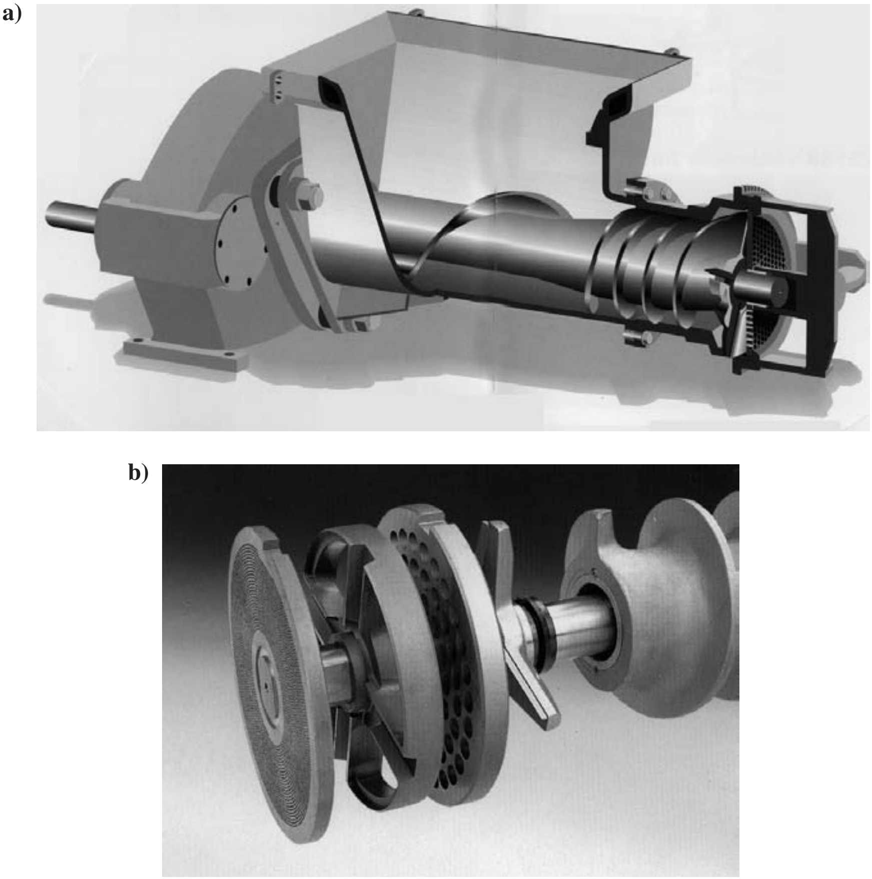

Figure 8.2. *Illustration of a Meat Grinder (a) and a Two-Cutting Set System (b). Courtesy of Weiler and Company, Inc., Whitewater, WI, U.S.A., and Convenience Food Systems, B.V., Bakel, The Netherlands, respectively.*

should be stopped, and the connective tissue (or any other obstacle) trapped behind the plate should be removed. Some of the new designs have a system that continuously collects and removes connective tissue and bone particles through an opening in the center of the plate, while others force the hard particles to the outside of the plate. This material is carried away by a pipe/hose connected to the opening so it does not get mixed in with the ground meat. In order to increase efficiency, some grinders have two sets of knives and plates [Figure 8.2(b)]. The size and number of blades, as well as the plates' openings, can vary depending on the degree of grinding required. Sometimes, if a large degree of size reduction is required, the meat will be ground first through a large opening plate and then a smaller hole plate (e.g., kidney plate with openings of about 50 × 20 mm, followed by a 5 mm plate). Regrinding of meat and spice mixtures that have been blended in a mixer (see next section), is employed in products such as summer fermented salamis, where a good mixing of the starter culture (i.e., mostly lactic acid bacteria; see Chapter 9) is desired.

Flaking

Partially frozen meat chunks or blocks can be flaked by shaving off small pieces. The machine has a circular cutting head and an impeller that spins at a high speed. The meat is pushed close to the knives by the resulting centrifugal force (Figure 8.3). The size of the flakes is determined by the spacing within the vertical knives of the cutting head. This method eliminates the mechanical squeezing of the muscle fibers in a conventional grinder, which can result in higher moisture loss from the meat (e.g., lean muscle contains about 70% moisture). The meat particles obtained from the flaker has a large surface area and can be easily used in restructured meat products where a muscle-like texture is reconstructed from small pieces of meat.

Chopping

The meat is passed through a set of cutting knives, and the degree of chopping is controlled by the speed of the blades, their number and the number of passes through the knives. This process is usually designed to result in very small lean meat and fat particles. This is achieved by the small gap between the cutting knives and the bowl [Figure 8.4(a)]. The process of chopping is commonly

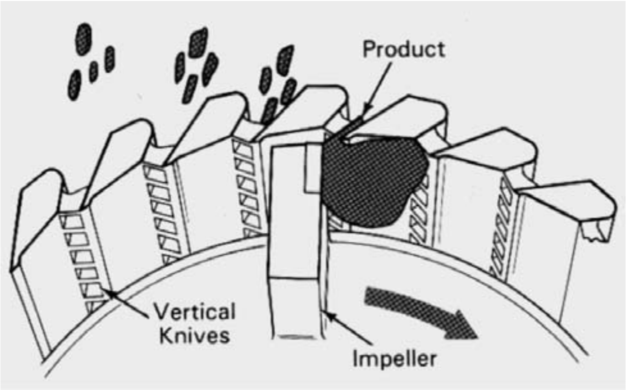

Figure 8.3. *Illustration of Flaking Equipment. Actual Cutting Head and Impeller: Showing the Principle of Flaking. Courtesy of Urschel Laboratories, Inc., Valparaiso, IN, U.S.A.*

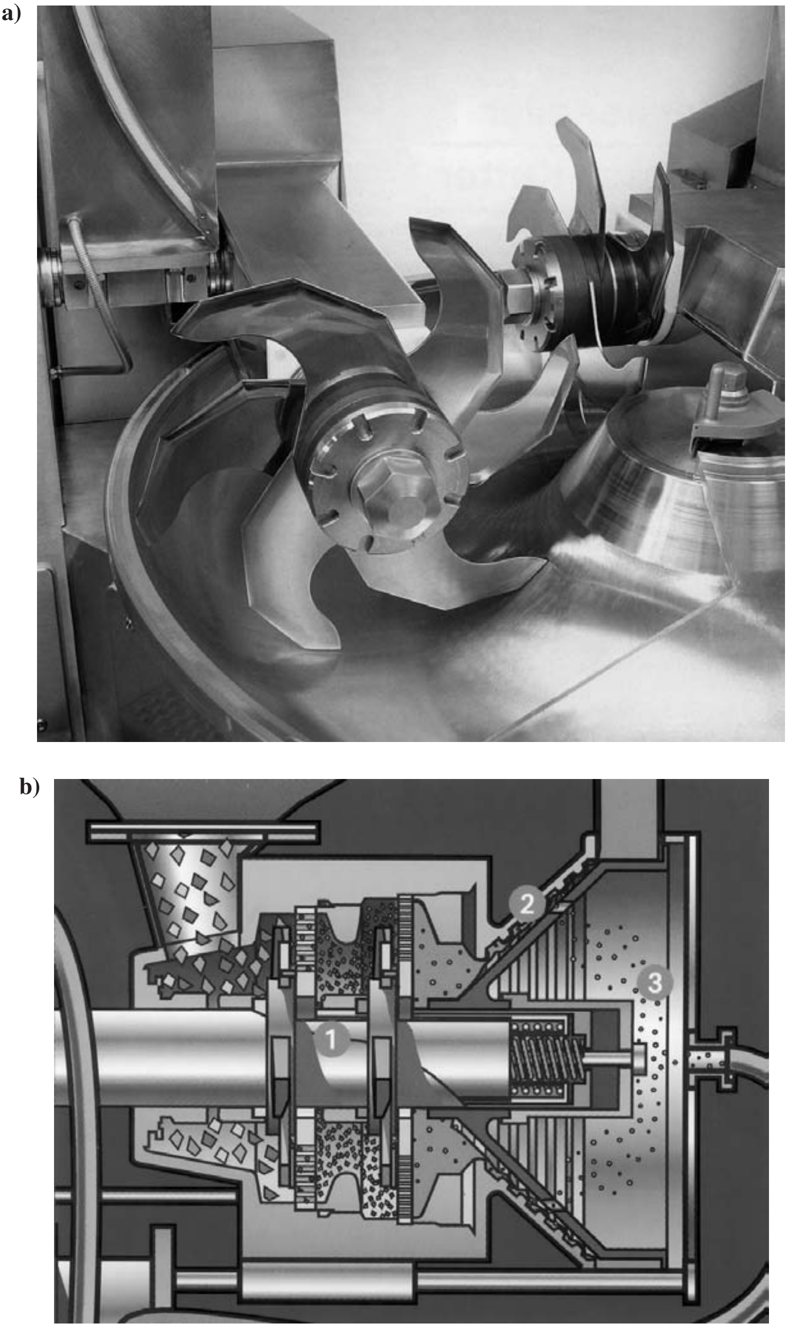

Figure 8.4. *Illustration of a Bowl Chopper (a) and an Emulsion Mill (b) Used to Prepare Finely Comminuted Meat Products. This Specific Design of a Bowl Chopper Has a Two-Cutting-Head Configuration, Each with Six Blades; Note the Close Gap between the Blades and Bowl. Courtesy of Convenience Food Systems, B.V., Bakel, The Netherlands.*

used for producing fine comminuted, sometimes called emulsion-type, products such as frankfurters and bologna (see recipe in Chapter 9). Fine emulsion-type meat products with coarse inserts (e.g., smoked turkey sausage; see the recipe in Chapter 9) can also be made by first preparing the fine emulsion and later mixing coarse inserts by using the reverse mode of the chopper. The two common chopping devices are the bowl chopper and the emulsion mill. In a bowl chopper, the meat is placed in a cutting bowl, which rotates at a relatively slow speed [15 to 30 revolutions per minute (rpm)], while the meat is chopped by a set of sickle-shaped knives (three to 15) at a speed of a few thousand rpm. In order to speed up the process, some new designs have two sets of cutting heads as shown in Figure 8.4(a). An emulsion mill (also called an emulsifier) combines the two principles of grinding and chopping. In a mill, preground meat is fed from a top hopper and passed through a very fast rotating blade and a perforated plate. The blade and plate are arranged in a similar configuration as in a meat grinder and can be positioned vertically or horizontally. Figure 8.4(b) shows a horizontal configuration that also has an in-line vacuum system.

Removing the air from the product is beneficial in minimizing problems such as lipid oxidation (e.g., off flavor development, color fading) and air pockets in the final cooked products. Vacuumed bowl choppers are popular in the industry. If air removal is not done at this stage, it can be done during the stuffing operation; however, it is not as efficient and is easier to apply during the chopping operation when a large surface area is created. Emulsion mills operate at a very high speed, and the meat is subjected to considerable friction, resulting in a fairly fast temperature rise (e.g., 5–8°C in a few seconds). Therefore, special care should be given to operating such equipment. A discussion on the risk of exceeding a certain chopping temperature (usually 8–12°C) during the preparation of finely comminuted poultry products can be found in Chapter 9. However, some of the main advantages of a mill are that it can process large volumes in a continuous manner and achieve a high degree of meat tissue disintegration.

MIXING

Mixing is another very common step in producing meat products. It is used to achieve four major goals:

- provide uniformity when different meat sources are used
- mix non-meat ingredients (e.g., salt, spices) within the meat batter
- assist in extracting salt-soluble proteins from the muscle by providing mechanical agitation
- enhance absorption of brine solution into the muscle structure

Different mixer designs are available on the market. The paddle mixer uses paddles to mix the meat in a bowl/chamber (Figure 8.5), and the ribbon mixer

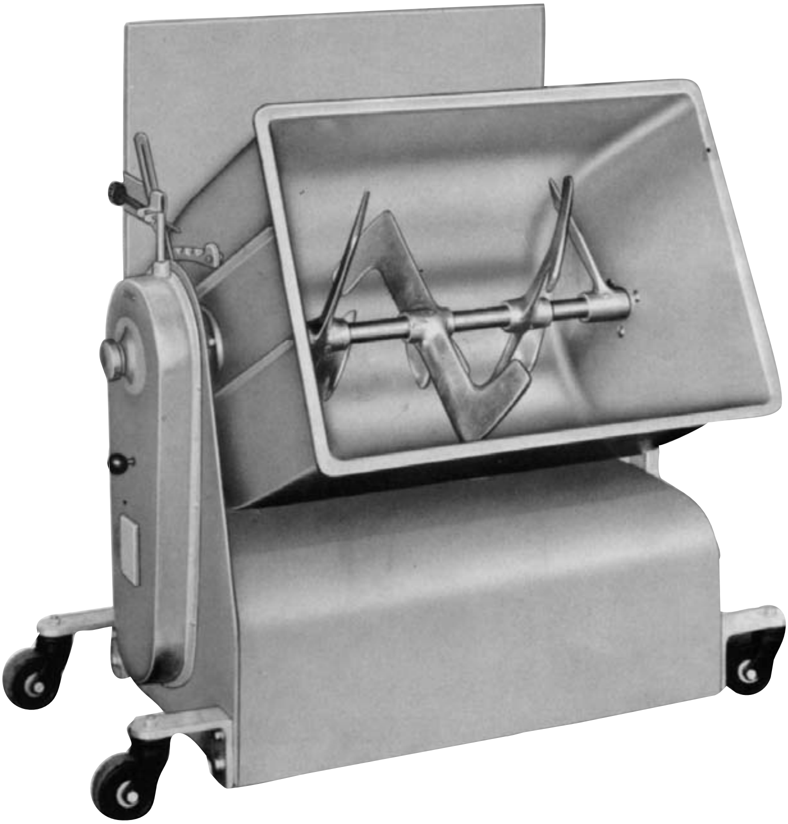

Figure 8.5. *Illustration of a Paddle Meat Mixer. Courtesy of American Meat Equipment Corp., Montebello, CA, U.S.A.*

has blades mounted on a horizontal shaft. With any mixer, blending should be precisely controlled to ensure uniform mixing. This can be checked (i.e., initially when devising a new time schedule; occasionally as a quality control measure) by using a food coloring, mustard seeds or small ice cubes placed at one or few corners of the mixer. To ensure proper mixing, the mixer should be filled only to the top of the blades or paddles, otherwise proper blending will not be achieved. Over-mixing should also be prevented because it can result in too much muscle fiber separation. Coarse-ground products (e.g., turkey breakfast sausage, salami) are prepared in a mixer after grinding the raw meat to the desired size. In addition, meat ingredients to be chopped by an emulsion mill are commonly mixed prior to comminution. This ensures uniform distribution of all the ingredients (i.e., particularly important for the emulsion mill process where very little overall mixing takes place during the single pass through the cutting head).

Pre-blending is another common procedure employed by the industry, where the meat is blended with salt a few hours (e.g., one to two hours or overnight) prior to making the product. This allows extra time for the salt to solubilize the meat proteins and improve water-holding capacity, as well as physically bind the meat particles. Sometimes, only the lean meat portion is pre-blended with all the salt so the processor can obtain a high salt concentration in the lean meat portion (see Figure 9.1 showing that a salt concentration of about 5% will provide maximum water binding or, in other words, lower shrink; average salt content in poultry products on the market is 1.5–2.5%). In general, salt is usually added at the initial mixing stage to the lean meat portion (i.e., before adding the fat), because its uniform distribution is extremely important in manufacturing high-quality products (Barbut, 1999).

INJECTING

Injection equipment is used to introduce the brine solution (water, salt and flavorings) into large whole muscle products. In the past, the two major curing methods used for whole muscle products were dry curing (i.e., rubbing the dry ingredients on the surface of the meat) and brine soaking. Both processes are time consuming, especially when dealing with large muscles (e.g., whole turkey breast), and today, mechanical injectors are commonly used by the industry. The injectors can consist of a single needle operated manually or a few dozen needles automatically controlled to deliver a precise volume of brine (Figure 8.6). The composition of a typical brine solution is shown in Table 8.1. The proportions used are designed to provide the desired quantity of salt, sugar, nitrite, water, etc., in the product. The delivery of the exact amount is very important in meeting flavor requirements (e.g., saltiness, sweetness) and government regulations (e.g., nitrite concentration; see Chapter 9). Table 8.1 also provides an illustration of flavor problems that might arise if mistakes occur in the delivery system. If a 10% injection is desired, a problem with a few clogged needles will result in a lower than expected salt concentration (e.g., half the salt if only 5% is delivered). Special care should also be given to the uniformity of the injection process to prevent high salt and/or nitrite concentrations in localized areas where bones, etc., are present [Figure 8.7(a)]. This can be achieved with special sensors attached to the needles that can gauge pressure and distance. High concentrations of salt and/or nitrite can cause flavor and color defects (e.g., cured and noncured colored areas; nitrite burns due to extremely high nitrate are very rare) in the final product. Therefore, the injector should be constantly monitored, and quality control checks of pumped weight should be performed on a regular basis. The calculation for percent pump and percent yield are shown in Table 8.2. The finished product weight is used to calculate the actual salt, sugar, etc., concentration needed to be injected into the raw meat in order to achieve a certain flavor. During cooking, moisture evaporates (unless moisture-proof cas-

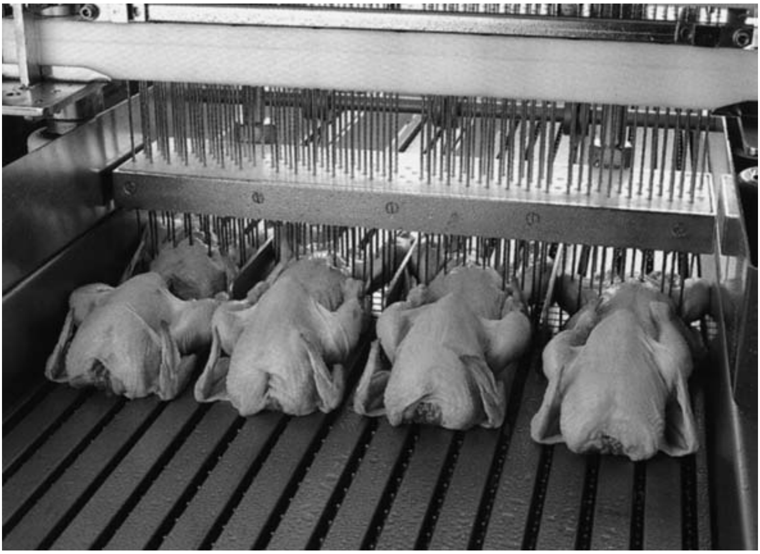

Figure 8.6. *Illustration of a Brine Injector. Courtesy of Schroder Maschinenbau Gmbh, Werther, Germany.*

ings are used), but salt, sugar, etc., do not evaporate and are actually concentrated in the product. Therefore, knowledge of all processing parameters is crucial in achieving the desired product.

Another consideration is the type of needles used for injection. Overall, the needles must be narrow enough not to cause any damage to the appearance

Table 8.1. An Example of a Brine Curing Formula

Ingredient	Concentration (%)
Water	75.5
Salt	17.5
Sugar	3.5
Phosphate	3.0
Na-Ascorbate	0.35
Na-Nitrite	0.15

Illustration of the importance of Precise Control of Injection rate.

% Pump	Salt in Product (%)
5	0.875
10	1.750
15	2.625
20	3.500

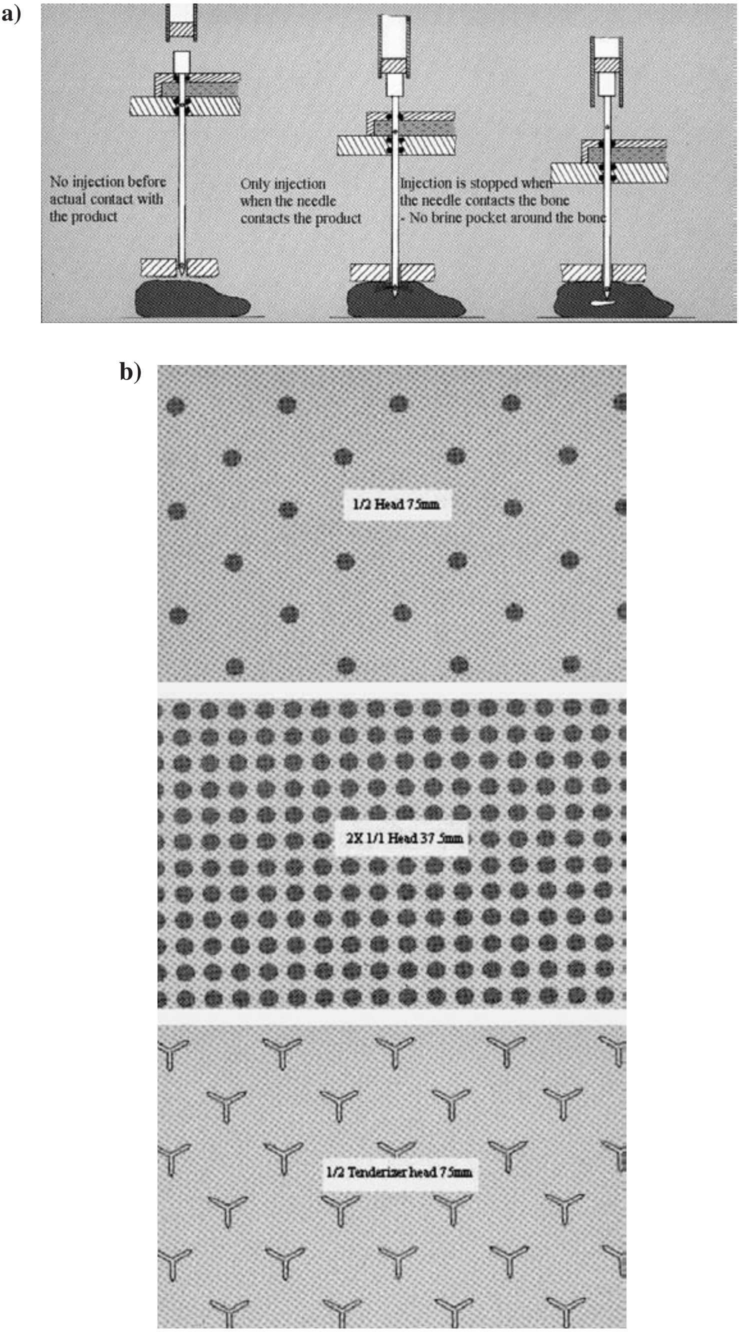
a)
No injection before actual contact with the product
Only injection when the needle contacts the product
Injection is stopped when the needle contacts the bone
- No brine pocket around the bone
b)
1/2 Head 75mm
2X 1/1 Head 37.5mm
1/2 Tenderizer head 75mm

Figure 8.7. *Illustration of Proper Brine Injection Principles (a) and Examples of a Few Needle Injection Patterns (b) that also include an Arrangement for Blade Tenderization of Meat (i.e., Mounted on the Same Machine). Courtesy of Wolfking Belam, Uden, The Netherlands.*

Table 8.2. Calculating Processing Yields.

	Example
$\% \text{ Pump} = \dfrac{\text{Pumped weight} - \text{Green weight}}{\text{Green weight}} \times 100$	
Green weight (initial meat weight)	200 kg
Pumped weight (meat + brine)	220 kg
$\% \text{ Pump} = \dfrac{20}{200} \times 100 = 10\%$	
$\% \text{ Yield} = \dfrac{\text{Finished weight}}{\text{Green weight}} \times 100$	
Finished weight = weight after cooking, smoking or drying	190 kg
$\% \text{ Yield} = \dfrac{190}{200} \times 100 = 95\%$	
If finished weight is:	210 kg
$\% \text{ Yield} = \dfrac{210}{200} \times 100 = 105\%$	

of the muscles. This is especially true with products that are known to have a weak connective tissue structure (e.g., breast meat from large turkeys).

TENDERIZATION AND MACERATION

In cases where tough meat is used, such as with thigh meat, a tenderizing process can be employed [Figure 8.7(b)] where more injection needles, larger needles and/or blades can be used. Macerating blades that slash the meat surface (i.e., a few mm deep) are sometimes used to increase the surface area available for protein extraction and disrupt the connective tissue covering the uncut muscles. This, in turn, can result in better binding during cooking. After injecting the brine, it is common to tumble the meat to achieve an even distribution of the brine, enhance brine absorption and facilitate the extraction of salt-soluble proteins (Barbut, 1999).

TUMBLING AND MASSAGING

Tumbling and massaging are two procedures designed to basically achieve the same goals of proper brine distribution and protein extraction from whole/chunked muscle products. In both processes, the meat is subjected to a certain degree of agitation that assists in distributing the salt and solubilizing myofibrillar proteins. Tumbling is done in a rotating drum that can have different baffles/ribbon designs on the sides (Figure 8.8). Massaging is done in a stationary mixing vessel where a paddle(s) is used to slowly move the meat.

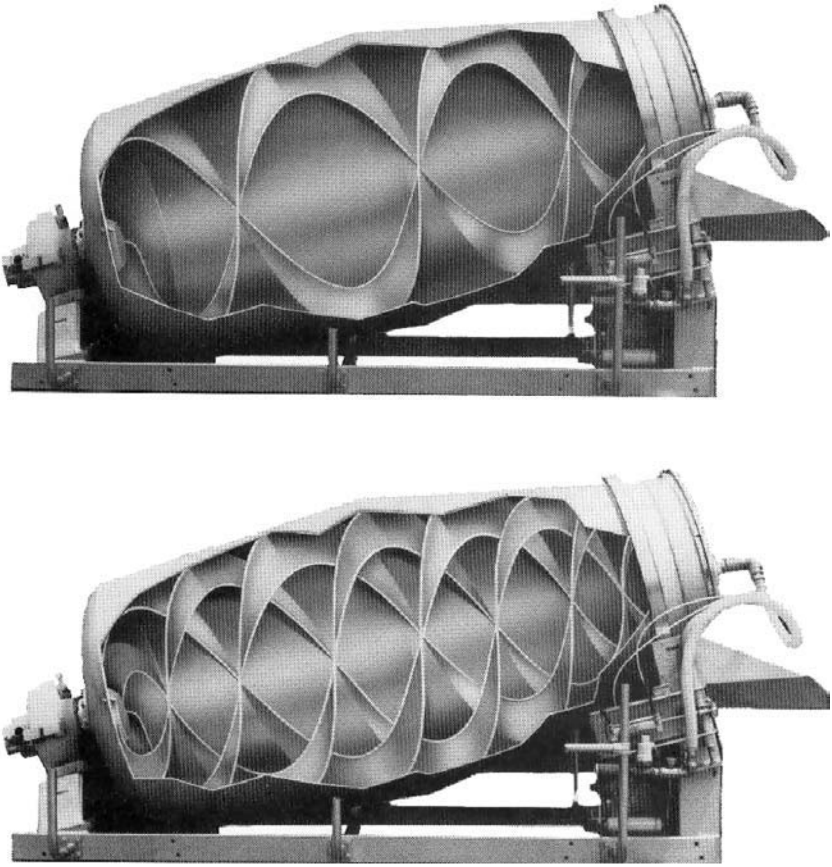

Figure 8.8. *Illustration of Meat Massagers. Courtesy of Challanger RMF, Grandview, MO, U.S.A.*

The massaging action is considered more gentle because there is no lifting and dropping of the meat, as is the case in a tumbler.

However, with some new tumbler designs, the manufacturers claim that a gentle mixing, similar to a massager, can be achieved. For example, the two- and four-helical ribbon designs shown in Figure 8.8 help to provide a gentler mixing, compared to tumblers only equipped with horizontal baffles (located on the drum's wall) that lift and drop the meat during their rotation. The helical ribbons help to advance the meat toward the upper end of the tumbler and then displace the meat toward the other side. This is important for muscle products with inherently weak connective tissue structures (e.g., turkey breast meat from large toms). Commercial tumbler and massager capacities range from a few kg (laboratory models) up to 10 tons. The degree of fill (meat volume as a percent of total volume) is important in achieving adequate tumbling/massaging without damaging the meat structure (e.g., low fill of a large tumbler can result in dropping the meat from too high a level and potentially weakening the structure).

Temperature control is another important factor, and tumblers/massagers are usually placed in a refrigerated area and/or have a double wall construction that allows fast cooling by circulating a cooling agent. Keeping the meat cold and constantly removing the heat created by the friction of the moving meat chunks is important in obtaining good protein extraction and in suppressing microbial growth. The agitation, which can be applied for one to several hours (e.g., slow or intermittent overnight; see recipes for oven roasted turkey breast products in Chapter 9), helps disrupt some of the tissue structure, assists in distributing the brine solution and develops a protein exudate that will later serve as a “glue” to bind the meat chunks during cooking (i.e., the heat denaturated proteins form a binding gel matrix). Operating under vacuum helps in removing the air bubbles from the exudate and might also assist in protein extraction. Most commercial tumblers/massagers are equipped with vacuum capabilities (e.g., the hose seen coming out of the tumbler’s lid in Figure 8.8 is for vacuum application).

STUFFING AND LINKING

Manual, semiautomated and fully automated machines are used to stuff raw meat batter into casings. Stuffers vary in size and degree of automation but generally can be divided into two basic types: piston and pump stuffers (Pearson and Tauber, 1984). The piston is air driven, using manual or electrical energy, and forces the meat from a cylindrical storage chamber/barrel through a stuffing horn. Hydraulic stuffers are commonly positioned in a vertical way, and the moving plate pushes the meat to the top. Manual stuffers are usually positioned horizontally, and the moving plate pushes the meat to the end of the barrel which is fitted with a horn. The diameter of the horn, stuffing speed and pressure are controlled by the operator and should match the size and type of the casings used. Different casings (e.g., natural collagen, manufactured collagen, cellulose, plastic) are used for different types of meat products (see Chapter 9). The type of casing used should always match the stuffing equipment used (e.g., high-speed automated equipment requires strong, uniform casings such as cellulose).

A pump-operated stuffer (Figure 8.9) employs an impeller to move the meat. The impeller usually has feedback and pop-off connectors so a vacuum can be drawn to evacuate trapped air within the meat batter. Applying vacuum is optional, and vacuum stuffers are more expensive but are advantageous in providing high-quality products. Large air pockets left in the batter might later show as empty voids in the cooked product, filled with gelatin (melted connective tissue) or melted fat. It is important to minimize the presence of such

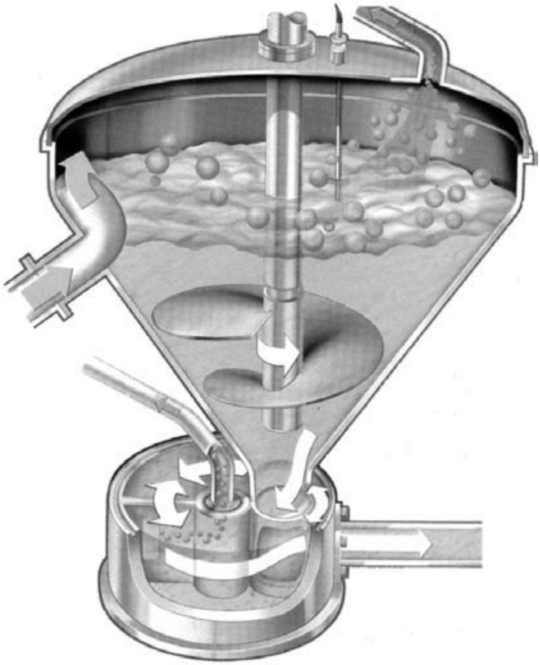

Figure 8.9. *Illustration of a Rotary Vane Pump Meat Stuffer with a Vacuum Application. Courtesy of Handtmann Piereder Machinery Ltd., Kitchener, ON, Canada.*

voids, because products with an excessive amount of large voids or small air pockets will be rejected by the consumer. (Note: as indicated before, vacuum choppers are more effective in removing small air pockets from emulsified products.) In addition, evacuating the air can help minimize oxidation problems and prolong the shelf life. In the particular design shown in Figure 8.9, the exclusion of air starts when the meat arrives in the hopper. (Note: this feature is not found in all vacuum stuffers.) Later, a feed screw transfers the meat to a pump where it continues to be subjected to vacuum. The single vane of the pump rotates through 270 degrees before reversing direction and starting another sweep cycle. At the end of each sweep, a combination of inlet-outlet valves rotate, directing the flow of the meat from the hopper into the cavity that is formed as the vane discharges the product. Pump-operated stuffers are recommended for finely comminuted products and finely ground products. When it comes to coarsely ground sausages and those having large particles such as fat and/or pickles, pimento, etc., some processors prefer the piston-type stuffer because the old-style pump stuffers could damage some of the particles.

After stuffing, the casings have to be closed at the ends. This is done by tying with a thread or fastening with a metal clip. Small diameter products can also be twisted or drawn together to produce links, either by hand or with special equipment. Large diameter items are tied or clipped at one end with a hanging tie and suspended from a smoke stick or hook so the entire surface is free from contact with the equipment or other products. This permits a good flow of air around the sausages in the smokehouse and prevents touch marks and spotting due to contact with adjacently hanging products. With long bologna (e.g., 120–150 cm or 48–60 inches in length) intended for slicing, the tendency is to use strong cellulosic casings and place the bologna on a screen in a horizontal position. This horizontal processing allows better utilization of casing material and aids in retaining a uniform cylindrical shape of the heavy product. If the heat capacity of the smokehouse is adequate, some reports suggest that more product can be placed in the smokehouse, compared to the amount held in the vertical hanging positions. For frankfurters and other small sausages, hand-linking is rarely done today. Using machines that stuff and link is now the acceptable practice. Today's machines will stuff and link from a few hundred to a few thousand kg/hr. Various processors currently use high-speed, sophisticated stuffing lines that are fully automated. The stuffing equipment is attached to linking and tying equipment which, in the case of a small diameter product such as frankfurters, can automatically hang the links on a continuous moving line that takes the product directly to the smokehouse. These high-speed linkers set the production economics of the sausage industry (Pearson and Tauber, 1984).

FORMING

Forming machines are used to form products such as patties and nuggets. These products are made from a mixture of ground and/or emulsified meat. The forming machine is basically a press with different templates that can be used to form any shape desired; some can also produce round meatballs. The meat is fed from a top hopper, either by gravity or by an auger, and is moved to fill a mold with the desired patty shape. The mold plate is usually made out of plastic or metal and can have a single cavity or multiple cavities. Once filled, there is a knockout mechanism that discharges the patties onto a conveyor belt. Programmable stacking and paper/film insertion mechanisms are also available on some models. Common equipment on the market operates at 20–60 strokes/minute and produces patties of 30–250 g.

The formed products do not hold together very well in the raw state. Therefore, to maintain the shape of the newly formed product, the patty/nugget is usually individually quick frozen (IQF), frozen in bulk, cooked or par-fried.

BATTERING AND BREADING

Battering and breading machines are used to uniformly apply a batter and breading coat onto whole muscle or formed products (e.g., patties, nuggets, as described above). The equipment is usually connected via a series of conveyor belts that carry the product through a combination of ingredients used to coat the product. Some of the belts are designed to vibrate and, thus, control the thickness of the breading layer (see a detailed description of equipment used in Chapter 10).

COOKING

Poultry products are consumed after they have been cooked. Heating can be done in water, steam or oil, or by hot air or infrared or microwave energy. Cooking results in distinct textural and flavor changes due to the denaturation of the different muscle proteins and production of various aroma/odor compounds, respectively. A detailed description of the textural changes is provided in Chapter 9 (see gelatin), and flavor changes are discussed in Chapter 13.

Hot air ovens, with or without smoking, are the most popular way of heat processing sausage-type products. The products are placed in a chamber, and the heat generated from a gas burner, an electrical element or thermal fluid is transferred to the products. An example of a modern spiral oven that employs hot fluid to cook meat products is shown in Figure 8.10. The amount of moisture in the air, air flow, temperature difference between the product and air (called by some delta-*T*), the size of the product and oven capacity are some of the main factors determining the rate of heating. Of particular importance is the relative humidity in the air (expressed as amount of moisture in the air at a given temperature), because water is a good conductor of heat and its presence helps deliver heat.

Cooking in water is a faster way of transferring heat into the product compared to using hot air. Steam kettles and water baths are used for cooking sausages and whole muscle products stuffed into a moisture-proof casing. In other cases, unpackaged meat cuts are directly immersed in water/soup. The latter is commonly done where prolonged moist heat is required to tenderize tough connective tissue (e.g., mature hen meat).

Frying is a very efficient way of transferring heat into the product because the temperature of the oil can be raised well above 100°C. Frying in oil also provides a crisp texture to the outside of the product and is desired in products such as fried chicken and breaded chicken nuggets. A detailed description of the frying operation is provided in Chapter 10, including an illustration of a continuous deep-fat fryer used (at 190–200°C) for battered and breaded products.

Grilling uses a gas flame or charcoal to cook/barbecue the meat. The high heat results in fast cooking and unique flavor notes. Some commercial grills consist of a heated belt that carries the product through the process.

Infrared heating is done by special infrared lamps that heat the surface of the product. The heat is then slowly transferred by conduction into the center of the product (see Chapter 7). This type of heating is mainly used for warming up cooked products, keeping products hot on a display counter and in combination with microwave heating when surface browning is desired.

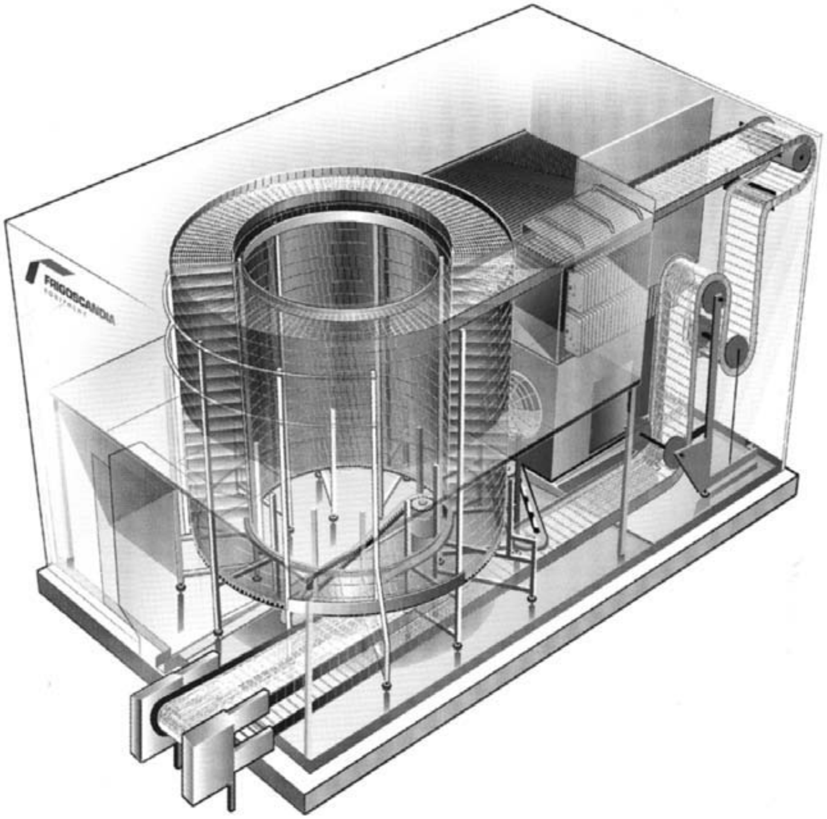

Figure 8.10. *A Spiral Oven Utilizing Thermal Fluid (Heated Away from the Oven) as a Heat Source for Cooking Poultry and Other Food Products. Courtesy of Stein DSI, Sandusky, OH, U.S.A.*

Microwave heating is one of the fastest ways of cooking. Heating results from friction of water molecule rotation due to rapid fluctuation in the electromagnetic field (915 and 2,450 MHz are used commercially; see Chapter 7). Because cooking is very fast, there is usually not enough time to develop the typical brown color on the surface of the product. Therefore, other cooking methods, such as infrared, are employed to provide surface browning. Low microwave energy is also used to defrost meat. However, special care should be taken because there is a large difference between the heating profile of water and ice (see Chapter 7).

SMOKING

Application of smoke, derived from burning wood, is one of the oldest means of preservation. It was done by placing meats over an open fire, achieving both smoking and drying. Today, however, products are only lightly smoked in a specially designed smokehouse (Figure 8.11), and smoke is mainly used to provide unique flavor notes. In such an application, some of the bacteriostatic compounds found in smoke (e.g., phenols, acids; see Chapter 9) are deposited on the surface, but it should be remembered that they do not penetrate more than a few millimeters beneath the surface. Various hardwoods (e.g., cherry, hickory, oak) are used to generate the smoke by burning moist sawdust in a chamber outside the smokehouse. Softwoods are not commonly used, but when employed, special care should be given to avoid bitter flavors. Overall, more than 300 individual compounds have been identified in wood smoke (Maga, 1989). In the past, the only way to smoke meat and other food products (e.g., cheese) was to expose the products to smoke derived from burning wood. Today, the processor can choose from different preparations of liquid smoke extracts that can be directly added to the product, used as a dip,

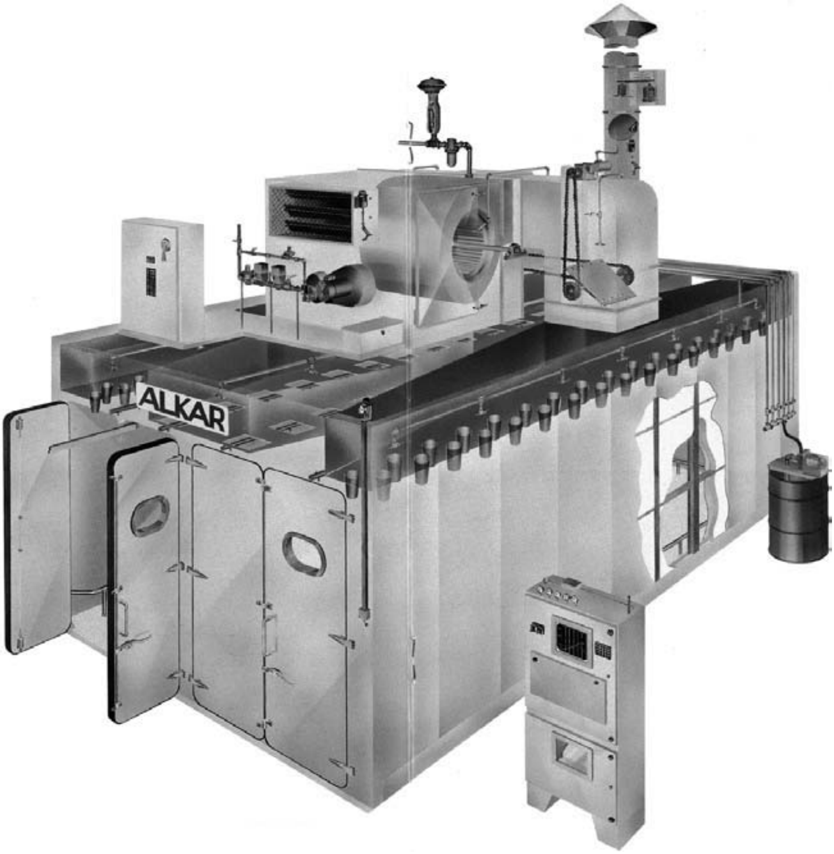

Figure 8.11. *Illustration of a Smokehouse. Courtesy of Alkar Inc., Lodi, WI, U.S.A.*

sprayed on the product/casings prior to cooking or atomized in the oven in place of traditional smoke (see Chapter 9).

Smoking and cooking are considered to be two separate processes; however, they are usually discussed together because they often occur in immediate succession or simultaneously at the same location (Rust, 1987). Modern smokehouses are equipped with heat application devices, so no moving of the product is required. It is important to realize that to achieve the best smoke application, the product should be in the raw state, because the denatured protein film, formed during cooking, will reduce smoke migration into the product. Therefore, smoking is done at low temperatures, even though some heat is often applied to dry the product's surface to ensure that the smoke will not be washed off. When liquid smoke is used, the product is dipped or sprayed prior to cooking. In all cases, casings permeable to smoke (e.g., collagen, cellulose) should be used. If liquid smoke is to be added directly into the raw batter, a special preparation (e.g., pH adjusted, low concentration) should be used, and there is no need to use permeable casings.

The smokehouse shown in Figure 8.11 has a heating and ventilation system (located on the top) that includes fans, dampers, heating elements and steam supply. The system is computer controlled so the operator can program and save all the parameters (e.g., heating, smoking, relative humidity, airflow) required for a specific process. Continuous smoke ovens (i.e., product is moving slowly through the house) are also used for the continuous production of products such as frankfurters.

SLICING AND DICING

Many cooked poultry products are currently sliced and packaged in the processing plant. This has resulted in the development of high-speed slicing equipment with precise portion control. The introduction of computerized weighing equipment has made a significant contribution in the development of modern slicing equipment. Figure 8.12 shows an example of a high-speed slicing line that also has a packaging module. The slicer (seen on the right) has a large circular blade that slices the product (loaded at a 45-degree angle) at a predetermined thickness. The products sliced by this machine are long products (e.g., 120–150 cm or 48–60 in bologna, mentioned earlier as products that

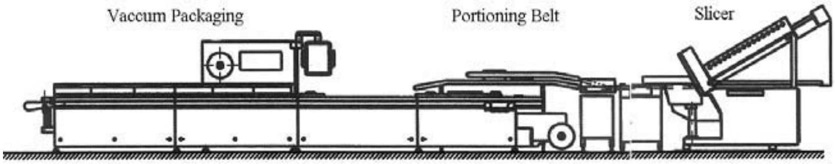

Figure 8.12. *Illustration of a High-Speed Slicing Line. Courtesy of Convenience Food Systems, B.V., Bakel, The Netherlands.*

are smoked and cooked horizontally) that are placed at the slicer's loading area. The machine can stack the slices or shingle them at a predetermined number and fashion so as to obtain a certain weight and presentation. The stacks, placed on a conveyor belt, are moved to an automatic weighing station. Those that are over- or underweight are automatically taken out of the production flow and corrected manually. The machine can be programmed to stack/shingle different diameter products with or without the insertion of paper/film in between individual slices or stacks. In addition, some machines can self-correct weight variations by a feedback control mechanism that increases/decreases slice thickness. This is possible due to the continuous monitoring of weight.

Dicing devices are used to prepare cubes, strips, etc., of products such as cooked chicken and turkey roll. The basic designs shown in Figure 8.13 can be used to cut frozen or tempered fresh meat, as well as cooked, boned products. In the model shown in Figure 8.13(a), the moving feed belt carries the product toward the knives, while the feed rollers hold the product flat as it moves it into contact with the cross-cut knives. The cross-cut knives slice the product into strips; the thickness of the strips can be changed by inserting more/less knives. The process can be terminated at this point or continued to dice the strips by the circular knives. Overall, many cube sizes are possible by spacing the knives at different distances from each other. Figure 8.13(b) shows a different configuration that also offers many possibilities by combining various circular and cross-cut knives.

PACKAGING

Most products are packaged prior to being shipped from the plant. The packaging material is used to protect the product from recontamination as a marketing tool (e.g., includes advertizing, cooking/serving suggestions), to keep the product's physical integrity, etc. The diversity of the hundreds of different new packaging materials and equipment used by the meat industry is beyond the scope of this book, and the reader is referred to textbooks such as Hanlon (1992) and Robertson (1993). However, illustration of two basic concepts of meat packing, namely vacuum packaging and skin packaging, is provided as well as a table showing the properties of some packaging films. Figure 8.14 shows a bag of meat placed in a vacuum chamber. Once the lid is closed, vacuum is applied and air is evacuated from the chamber; the level of vacuum can be adjusted in most machines. The bag is then sealed by applying heat to the seam area where a polymer capable of heat sealing is melted. The process can be done as a batch operation (i.e., each package placed and removed manually from the chamber) or on a continuous line, where the product is deposited on a special platform, covered with the lid, the air is pulled

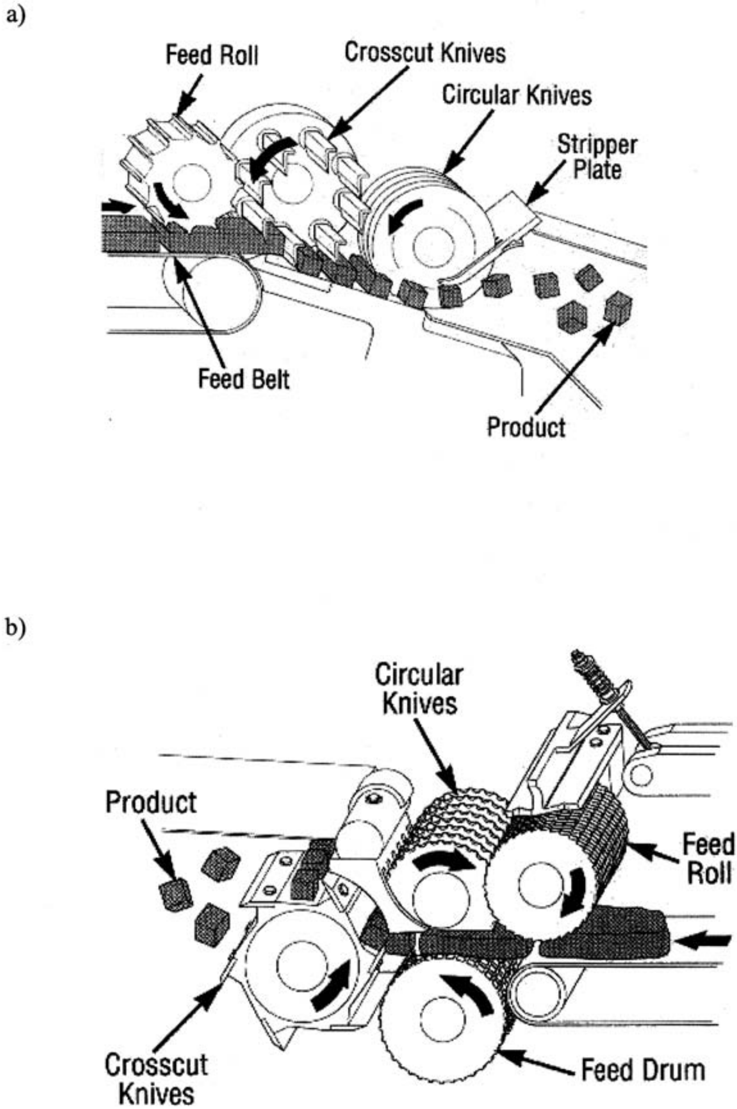

Figure 8.13. *Principle Operation of Two Dicing Devices. Model (a) Employs Cross-cut Knives First, and Model (b) Uses Cross-cut Knives as the Second Cutting Operation. Courtesy of Urschel Laboratories, Inc., Valparaiso, IN, U.S.A.*

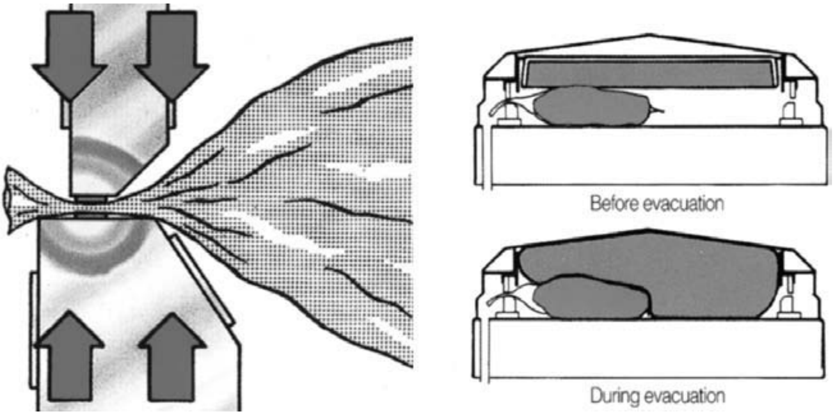

Figure 8.14. *Illustration of Vacuum Packaging. Courtesy of Supervac Gemsbh Inc., Vienna, Austria.*

out and the bag is then sealed. This is commonly done in a loop-type configuration in which enough time is allowed for air removal from this specially designed platform. The packaging film is usually composed of different layers, each contributing a specific function (e.g., oxygen barrier, heat sealant, strength), as will be discussed below.

Skin packaging of sliced or unsliced meat products is very common. The process involves placing the product on a film (soft or rigid) and later covering it from above with a flexible film (Figure 8.15). The product is placed manually or automatically (e.g., equipment shown in Figure 8.12) on a base web in the loading area. Location marks on the base plate ensure precise positioning. With each stroke of the machine, the product is indexed toward the sealing station. The flexible film drapes itself around the product [Figure 8.15(a)]. In the sealing station [Figure 8.15(b)] heat is applied at the seams, and the special polymer sealant (see example in Figure 8.16) is fused together, from both sides, to provide a good integral seam. The packages are then automatically separated by cutting around the seal's perimeter.

Table 8.3 shows the properties of different film materials. As indicated above, most packaging films used for poultry meat applications are composed of several layers (Figure 8.16). This is done in order to achieve several desired characteristics in a cost-effective way, while still obtaining a relatively thin workable film. Saran, which has low gas and water permeability, is a popular film used in multi-film production, together with other materials such as polypropylene which provides high stretchability. The illustration in Figure 8.16 shows only three layers, but some of the modern packaging films can have up to a dozen different layers including printed material, coating to protect the print, UV barrier, etc.

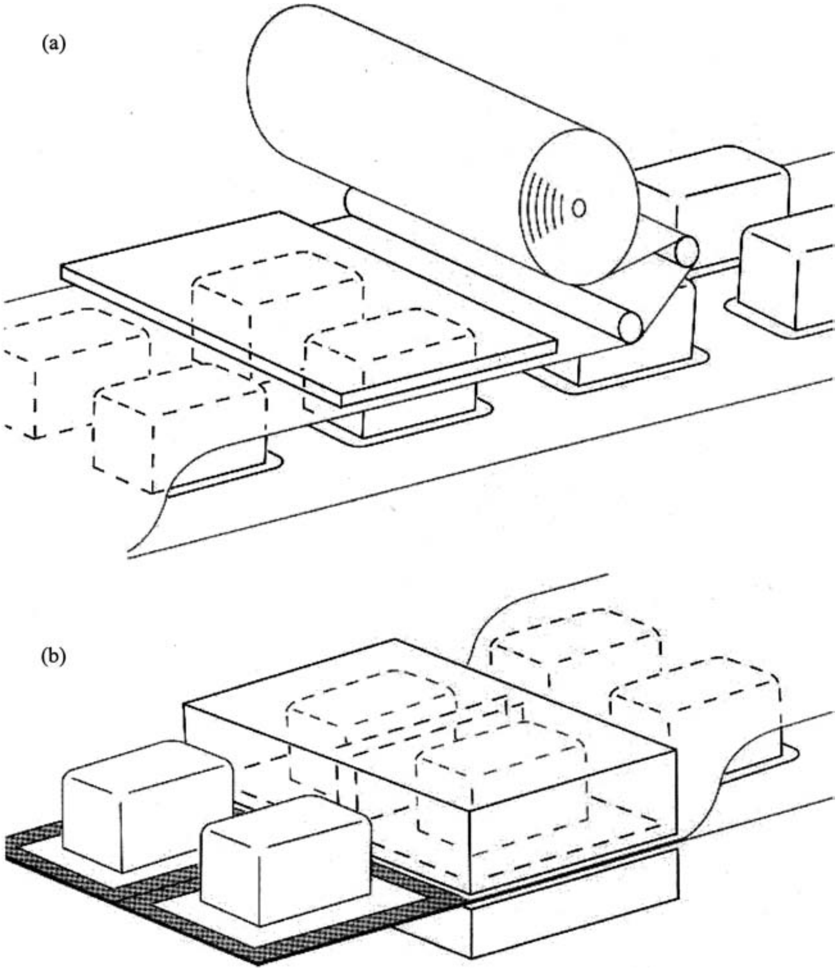

Figure 8.15. *Illustration of the Skin Packaging Concept Showing Entry to the Sealing Station (a) and the Sealing Section (b). Courtesy of Convenience Food Systems, B.V., Bakel, The Netherlands.*

METAL DETECTION

Metal detectors are now installed in most processing plants. Regulatory bodies such as the USDA have indicated that:

> The extensive exposure of some products to metal equipment such as grinders, choppers, mixers, shovels, etc., causes the possibility of metal contamination . . . therefore the use of electronic metal detectors is highly recommended . . .

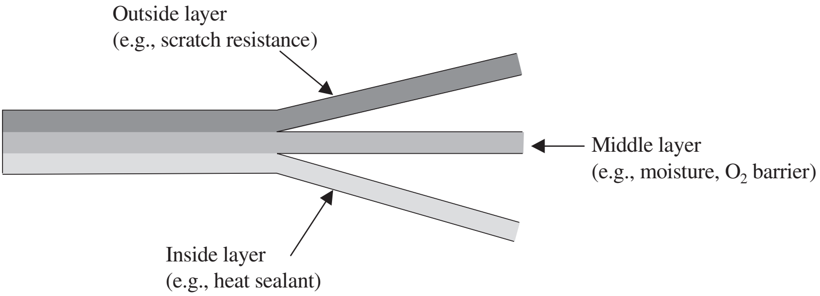

Figure 8.16. *An Example of a Multilayer Film with Each Layer Having a Specific Function.*

Overall, installing a metal detector can do the following:

- help prevent damage to processing equipment
- comply with quality standards by major customers
- avoid the cost and implications of consumer complaints and recalls

The most common types of metallic contamination in a broad range of industries include ferrous (iron), copper, aluminum, lead and various types of stainless steel. Of these, ferrous metal is the easiest to detect, and relatively simple detectors, or even magnetic separators, can perform this task well (Anonymous, 1996). Stainless steel alloys are extensively used in the food industry and are the most difficult to detect, especially the common nonmagnetic grades such as 316 (EN58J) and 304L (EN58E). The nonferrous metals such as copper and lead fall between these two extremes.

Metal detectors using a balanced three-coil system are common because they have the capabilities to detect small particles of nonferrous and stainless steel. The three coils are wound on a nonmetallic frame or former, each parallel with the other (Figure 8.17). The center coil is connected to a high-frequency radio transmitter. The two coils on each side of the center coil act as radio receivers or aerials. As these two coils are identical and the same distance from the transmitter, they pick up the same signal, and an identical voltage is induced in each. When the coils are connected in opposition, they cancel out, resulting in zero output. When a particle of metal passes through the coil arrangement, the high-frequency field is disturbed under one coil, changing the voltage generated by a few microvolts. The state of the perfect balances is lost, and the output is no longer zero. The resulting signal is processed and amplified. It is this phenomenon that is used to detect the presence of unwanted metal (Anonymous, 1996). To prevent airborne electrical signals or nearby metal items and machinery from disturbing the detector, the complete coil arrangement is mounted inside a metal case with an opening in the center to allow for the passage of the product. For suggested installation points,

Table 8.3. Properties of Selected Packaging Films. From Hanlon (1992). With Permission.

Type of Film	Water[a] Transmission	Gas Permeability[b]			Water Absorption	Dust Attraction	In-Use Temp. Range, °F	Heat Seal Temp., °F	Elongation, %	Impact[c] Strength	Tear[d] Strength Notched
		O_2	N_2	CO_2							
Cellophane, nitrocellulose-coated	0.3	1	1	13	High	Low	24–300	225	20	5.0	8
Cellulose acetate, 10% plasticizer	150	35	40	1000	High	Low	−15–140	350	40	2.5	15
Nylon	19	25	160	160	Medium	Medium	−100–200	—	100	2.5	75
Polyester oriented	1.7	4	1	16	Low	—	−80–230	275	—	12.0	80
Polypropylene	0.7	240	60	800	Low	High	0–275	350	300	1.0	330
Polyvinyl chloride, rigid	4	150	65	970	Low	High	−50–200	225	20	8.0	300
Saran	0.2	14	12	4	Low	Medium	0–200	280	60	6.0	20

[a] g loss/24 h/100 in^2/mil at 95°F, 90% RH.
[b] cc/24 h/100 in^2/mil at 77°F, 50% RH.
[c] Izod impact strength, ft • lb/in, notched.
[d] Elmendorf g/mil. (1 mil = 1/1000 inch).

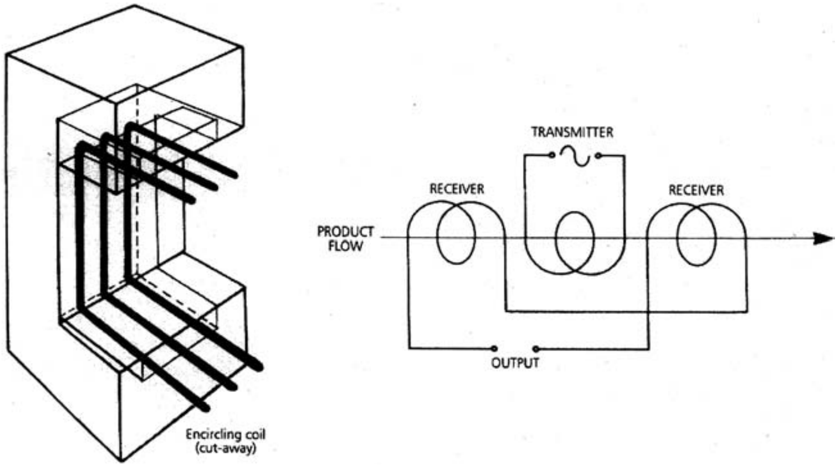

Figure 8.17. *Illustration of the Principles Used in Constructing a Metal Detector. Courtesy of Safeline Inc., Tampa, FL, U.S.A.*

such as after packaging sliced turkey ham or after freezing breaded chicken breast meat, see HACCP generic models in Chapter 12 (Figure 12.2—CCP #10, and Figure 12.3—CCP #4, respectively).

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CHAPTER 9

Poultry Products—Formulations and Gelation

INTRODUCTION

WITHIN the last couple of decades, many new processed poultry products have been introduced in the market. The poultry industry has taken the initiative to develop fresh, marinated and fully cooked products and has adopted some red meat recipes. All have helped to increase consumption and move away from seasonal demand. In the past, items such as whole turkeys were primarily sold in North America prior to Thanksgiving and Christmas. Such a pattern significantly limited the increase in sales of poultry meat. After the industry realized these limitations (e.g., demand concentrated within 1–3 months) and started to market smaller cut-up portions and further processed products, the situation improved. In the beginning, red meat recipes were modified to manufacture poultry products (e.g., frankfurters), and later, new technologies were developed exclusively for poultry (e.g., chicken nuggets). Chicken frankfurters were unheard of 25 years ago; however, after their introduction, they gained significant market share and currently represent about 20% of the North American market. Overall, the poultry industry successfully responded to consumer demand for more convenient food items including semi- and fully prepared items. The increase in poultry meat consumption (Table 1.4) has been the result of aggressive marketing, the favorable nutrition profile of the meat and the competitive price of poultry meat (see Chapter 1 for data on consumption, price, feed efficiency, etc.).

Today, consumers can choose meat products from a wide variety consisting of a few hundred different products. Becoming a knowledgeable consumer can be a challenge. To assist the consumer, various systems have been suggested for classifying meat products. One of the most common ways to classify products is to group them into six categories:

- fresh, such as fresh poultry breakfast sausage
- uncooked and smoked, such as Italian sausage
- smoked and cooked, such as frankfurters, bologna
- cooked, such as liver sausage and pates

Table 9.1. Examples of Various Further Processed Poultry Products.

Product	Comments
Smoked turkey breast	Whole muscle or restructured
Poultry roll	White and dark meat
Turkey ham	Cured dark meat
Turkey bacon	Layers of light and dark meat
Summer sausage	Fermented product
Poultry frankfurter	Fine emulsion, in small-diameter casings
Poultry bologna	Fine emulsion, in large-diameter casings
Poultry patties	Hamburger type, not cured
Breakfast sausage	Ground product, sold fresh or frozen
Chicken nuggets	Whole muscle or restructed
Fried chicken	Battered and breaded, sold un- or pre-cooked
Roasted, barbecued chicken	Prepared with dry heat, crisp skin
Jellied chicken loaf	Cooked meat held in a gelatin matrix

- dry/semidry or fermented, such as summer sausage, dry salami
- cooked meat specialities, such as luncheon meats, jellied products and loaves (Hedrick et al., 1994).

In addition, the development of new technologies represents two additional categories:

- restructured meat products, such as cutlets, where small bits and pieces of meat are made into a whole muscle fillet-like product (i.e., by using freezing, high pressure and hydrocolloid gums)
- surimi-like products, such as special chicken rolls, where minced meat is washed (to remove pigments and enzymes, see Chapter 6) and extruded to obtain a fiber muscle-like texture.

In this chapter, examples of the major processed poultry products (Table 9.1) will be discussed, recipes will be provided and manufacturing procedures will be presented. In addition, a discussion regarding non-meat ingredients used by the poultry industry, the formation of meat emulsions and protein gelation are provided.

PROCESSED POULTRY PRODUCTS

Smoked Turkey Breast

Smoked turkey breast is a premium product produced from either whole breast muscle or its portions. A brine solution (i.e., water, salt, spices and sometimes gums) is added to the muscle often by direct injection (see Chapter 8), prior to smoking and cooking. The meat is massaged or tumbled after brine injection to assist in moisture absorbing and achieving an even distribution of the non-meat ingredients within the muscle. The latter is important in the processing of any meat product, as an uneven distribution of salt, etc., can cause serious flavor, color and textural problems. Hydrocolloid gums such as carrageenans are often added to assist in holding the injected brine that can reach 30–50%. Non-meat proteins (e.g., soy concentrate/isolate, whey proteins) can also be added for the same purpose (see White Turkey Roast recipe in this chapter). Additives, such as lactate, are sometimes added for preservation. The breast muscle is then stuffed into a netting (the muscle can be covered with skin), smoked and cooked in a smokehouse until an internal temperature of at least 70°C is reached.

Poultry Roll

Poultry rolls can be made from dark meat, white meat or their combination. The meat is obtained from breast meat, leg meat, trimmings and the skin of turkey/chicken. In this product, pieces of meat are bound together to form a coherent product. Salt is added to extract the salt-soluble protein (mainly actin and myosin) that contributes to binding the meat pieces and holding moisture and fat within the product; see a more detailed discussion on salt functionality later in the chapter. The skin and some of the trimmings are usually finely chopped (the term “emulsified” is often used by the industry, even though no true emulsion is formed) to facilitate the binding of the fat. Seasonings are added to provide flavor. Moisture is added to compensate for cooking losses and to improve the juiciness of the product. If added moisture exceeds a certain level (limits vary in different countries) of the raw meat, the product should be labeled as a water-added chicken/turkey roll. The meat pieces are mixed together with the non-meat ingredients until the meat becomes sticky (i.e., used as an indication of good protein extraction) and all the added moisture is absorbed. The mix is then stuffed into casings, and the product is cooked either in a water bath or an oven, depending on the casings used, equipment available, market preference, etc.

Turkey Ham

Turkey ham is typically manufactured from turkey thigh meat. The product is usually leaner than the traditional pork ham. In the initial manufacturing step, a brine solution (i.e., water, salt, phosphates, flavorings and nitrite) is added either by injection or marination of small meat pieces. Tumbling is commonly used when brine is injected or used as a marinating solution to help achieve maximum absorption, even distribution of the curing ingredients and extraction of the salt-soluble proteins to the surface, which is important for binding the muscle chunks together during later heating. The meat is then stuffed into fibrous casings that determine the shape of the final product (round, oblong) and size. The ham is smoked, or smoke flavorings are added to the raw batter, and cooked to at least 68°C (see the recipe in this chapter).

Summer Sausage

Summer sausage represents a group of fermented meat products where commonly a lactic acid bacteria culture is added. The product can be made from dark poultry meat, skin and fat, but usually some pork meat and fat are included; pork fat is added because it is more stable and harder at room temperature. In this process, lactic acid bacteria are used to lower the pH of the product from about 5.7–4.8 and also to add unique flavor notes. In the past, microorganisms from a previous successful batch were introduced into a new batch, and the product was allowed to ferment. Today, the industry mainly uses commercial starter cultures with a known composition of microorganisms (predominantly lactic acid bacteria). The producer can select from cultures that grow at different temperatures and produce distinct flavor compounds. Recently, a lot of progress has been made in the field of starter cultures, mainly through the use of genetic engineering, where desirable characteristics from one strain can be moved to another. Overall, the use of a starter culture is highly recommended because it ensures that lactic acid bacteria dominates the fermentation (commonly added at about 10^7 per g), suppresses pathogens and produces the desired flavors. Recent outbreaks of *E. coli* O157:H7, associated with dry fermented sausages containing beef, have put more pressure on the industry to use starter cultures. The degree of fermentation can be controlled by the quantity of the carbohydrate added (i.e., an energy source for the microorganisms) or by continuous pH monitoring. After the fermentation (1–2 days with a starter culture), the product is either smoked, cooked or only dried. The dry product is usually shelf stable due to its low pH (4.6–5.0) and low water activity ($A_w < 0.90$).

Frankfurters and Bologna

Frankfurters and bologna are examples of finely comminuted meat products that have homogenous appearances. Leg meat, trimmings, skin and/or mechanically deboned meat are usually used as raw materials. When the relatively lean leg meat is used, fat and skin are added. The meat is finely chopped in a bowl chopper or an emulsion mill (see Chapter 8) that efficiently chops the meat particles and emulsifies the fat. Salt is added to extract the meat proteins that are essential in binding the small meat particles and stabilizing the fat globules within the protein matrix (Barbut and Findlay, 1989). Nitrite is added to inhibit *Clostridium botulinum* growth and provide the typical cured meat color (see Chapter 13). The meat batter is then stuffed into cellulose casings, smoked and cooked in a smokehouse. Because frankfurters are such a high volume item, some processors have constructed dedicated lines to continuously make this product. As with other meat products, low microbial contamination and refrigerated temperatures are important in prolonging the shelf life (see Chapter 11), where some manufacturers guarantee a shelf life of ≥50 days.

Chicken Nuggets

Chicken nuggets are one of the most successful poultry products introduced in the 1980s. Originally, the product was prepared from a single piece of slightly marinated breast meat that was battered and breaded. Later, nuggets made from trimmings, dark meat, skin, mechanically deboned meat and their combinations started to appear on the market. The product is usually prepared by marinating and mixing the meat pieces with a brine solution (i.e., water, salt and flavorings) until all the solution is absorbed. The meat is then put through a forming machine that creates the desired product's shape (i.e., square, oval, dinosaur), followed by battering, breading and deep-fat frying. Frying is done to preserve the product shape, assure breading adherence and to provide the typical crispy texture of the breading (see Chapter 10, which is devoted to battered and breaded products).

NON-MEAT INGREDIENTS

Different ingredients are added to processed meat products for a variety of reasons. Some of the main reasons are to: assist in protein extraction, enhance flavor, provide new flavor notes, bind moisture, increase juiciness, improve texture, modify texture, add bulk, enhance color, improve sliceability, lower formulation costs, and extend shelf life.

Additives

The non-meat additives can be divided into several groups. They include salt (sodium chloride, phosphate), curing salt (nitrite), water, spices, binders (e.g., high protein items such as whey, soy, egg and starches) and fillers (e.g., low protein items such as cornstarch). Each has its own unique role in the formulated product. Limits can be imposed on the addition of different non-meat ingredients. The amounts permissible are usually indicated in each country's Meat Inspection Regulations. Some ingredients such as nitrite are precisely controlled, while others such as soy protein usually have only a maximum limit for addition. For example, 3.5% of soy can be added by itself, or in combination with other binders, in a variety of cooked sausages produced in the United States; if one exceeds this limit, the product's name should include the words "soy added." In many countries, all the ingredients added to a meat product must be listed on the label. Below is an example of a typical ingredient list used in North America, where the additives are listed in descending order:

> Product name: Chicken frankfurters. Ingredients: Mechanically deboned chicken, chicken, water, wheat flour, salt, modified cornstarch, spice, dextrose, sodium erythorbate, sodium nitrite, smoke flavoring.

The most common non-meat additives used by the poultry meat industry are described below.

Salt or sodium chloride (NaCl) is the most widely used ingredient added to meat products. It provides three major functions:

- assists in protein solubilizing
- enhances and provides flavor
- alters microbial growth

Extracting the salt-soluble proteins, mainly myosin and actin, is essential for further meat processing. In raw meat batters, these proteins can bind moisture and increase water-holding capacity (WHC), assist in emulsifying fat particles in comminuted products by coating the fat globules and increase meat batter viscosity to facilitate fat incorporation. Upon heating, the extracted proteins coagulate and provide binding of the meat particles, bind moisture (minimize cooking losses) and form a coherent matrix to hold the melting fat.

High salt concentration in a meat product can stop or substantially suppress microorganism growth. In the past, high salt levels (10–15%) were used as the main means of preservation and could provide stable meat products. However, in today's meat products, much lower salt levels are used (e.g., 1.0–2.5%), and it is only in conjunction with other additives (e.g., nitrite) and appropriate refrigerated storage (see Table 11.1) that product safety can be ensured (Barbut and Findlay, 1989).

In terms of flavor, sodium chloride added to processed meats makes a substantial contribution. The classic salty taste is represented by NaCl and lithium chloride (LiCl). Other salts usually have additional flavors associated with them. Chemically, it appears that cations cause salty tastes, whereas anions inhibit salty tastes. In general, salts other than NaCl and LiCl have complex tastes consisting of a psychological mixture of sweet, bitter, sour and salty perception components, which have been shown to fall outside the traditional classic taste terms. Among the anions, Cl^- is the least inhibitory to the salty taste and does not possess a taste of its own. More complex anions cannot only inhibit the taste of their associated cations but can also contribute tastes of their own. Therefore, soapy tastes associated with certain phosphates, for example, are the result of a specific taste elicited by their anion.

The most acceptable model for describing the mechanisms of salty taste perception involves the interaction of hydrated cation-anion complexes with the Shallenberger and Acree AH/B-type receptor site. The individual structures of such complexes vary substantially, so that water, OH groups and salt anions/cations are associated with the receptor sites. Bitterness in salts appears to involve a different mechanism of reception that seems to be related to the sum of the ionic diameters of the anion and cation components of a salt. Salts with ionic diameters below 6.5 Å are salty in taste (LiCl = 4.98 Å, NaCl = 5.56 Å, KCl = 6.28 Å), although some individuals find KCl somewhat bitter. As the ionic diameter increases (CsCl = 6.96 Å, CsI = 7.74 Å, $MgCl_2$ = 8.50 Å), salts become increasingly bitter (Lindsay, 1985).

Sodium reduction in meat products was an important issue a decade ago and still is for some individuals suffering from hypertension. An important consideration in replacing NaCl with other chloride salts, besides the organoleptic factor, is the effect on the physical properties of the final product. Sodium chloride reduction by itself will result in lowered WHC of the raw meat batter, which, upon heating, will result in higher cooking losses, drier product and, if cooking losses are too extensive, a totally unacceptable product. The relationship between salt concentration and WHC is well established and is dependent on factors such as the amount and type of protein present, previous storage history and pH. In post-rigor lean poultry meat, gradually increasing the salt levels from 0–5% will decrease percent shrink up to a maximum obtained at around 5% salt (Figure 9.1). Further salt addition will result in decreasing WHC, a phenomenon known as "salting-out," as a result of increasing charges on the protein molecules causing a reduction in the binding of water molecules.

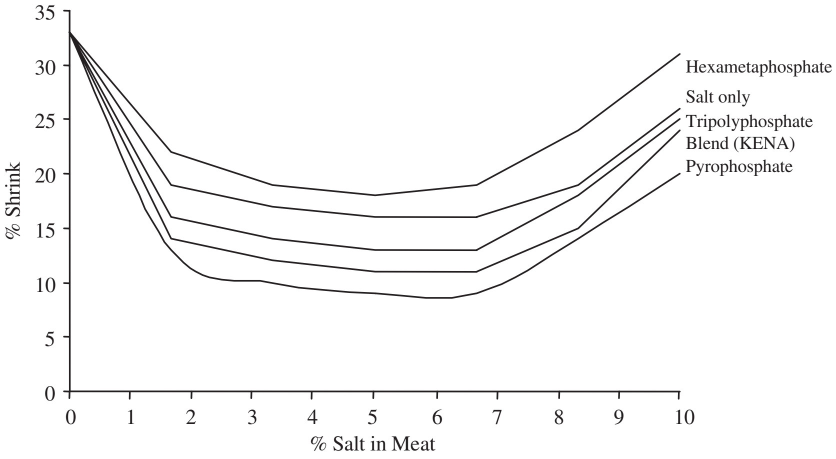


Figure 9.1. *Effect of NaCl on the Shrinking of Cooked Chicken Muscle (70°C) in the Presence of Salt and Polyphosphates (0.5%). Adapted from Shults and Wierbicki (1973).*

A processor should always try to use the highest quality salt possible. High quality refers to a low level of impurities (heavy metals such as iron, copper) found in the salt. These trace contaminants are known as pro-oxidants and can trigger fast lipid oxidation within the stored product, as will be discussed later in the chapter.

Nitrite/nitrate is known as a curing salt. It can be added as sodium nitrite ($NaNO_2$) or sodium nitrate ($NaNO_3$); both can also be purchased as a potassium salt. Nitrite is added at low levels, 100–200 parts per million (ppm) and provides four main functions:

- inhibits *Clostridium botulinum* spore growth
- provides the typical pink color of cured meat
- adds flavor
- assists in preventing oxidation

The chemical reaction of sodium nitrite added to a meat system is shown below:

$$NaNO_2 \rightarrow HONO + Na + H_2O$$

$$3HONO \rightarrow HNO_3 + 2NO + H_2O$$

The active compound is the nitric oxide (NO) that can inactivate the *C. botulinum* spores (see Chapter 11) and react with the myoglobin pigment to form the typical pink cooked color:

$$\text{Myoglobin} + \text{NO} \rightarrow \text{Nitrosomyoglobin} \xrightarrow{+\text{ heat}} \text{Nitrosohemochrome}$$

Typical “Cured Meat Color”

The reduction of nitrite to nitric oxide in an aqueous solution is rather slow. In a meat system, some of the muscle’s enzymes can participate in reducing the nitrite. However, in order to get a fast conversion to nitric oxide, the meat industry employs curing accelerators such as ascorbic or erythorbic acids that promote reducing conditions within the meat system. This is especially important in a continuous sausage production where the processor’s objective is to start cooking the product within 1 hour of adding the non-meat ingredients. In other cases, such as manufacturing dry sausages, a slow nitric oxide release is preferred, and curing accelerators such as sodium ascorbate or erythorbate are not always used. In this case, some processors are actually using sodium nitrate, which takes even longer to break down to nitric oxide.

Nitrite at high levels can be toxic, and therefore, the legal amounts permitted in meat products are regulated. In most countries, levels of 100–200 ppm have been declared as safe. It should be mentioned that processed meat products are not necessarily a high source of nitrite in our diet. In comparison, green vegetables such as celery have levels of about 300 ppm. In addition, bacteria in human saliva and in the gut are capable of producing even higher levels of nitrite. Nitrite added to meat products is depleted over time, especially during cooking, and a frankfurter with 150 ppm $NaNO_2$ added will show about 10–30 ppm or less at the point of purchase. Overall, it is estimated that meat products contribute only 5–10% of the total nitrite in our diet. There is also a concern in products that are heated to a high temperature (e.g., fried turkey bacon), where residual nitrite can react with secondary amines to form nitrosamines, which are potential carcinogens. Therefore, countries such as the United States mandate the use of a curing accelerator (e.g., 500 ppm ascorbate) in such products to assure a fast conversion of nitrite to nitric oxide and to minimize the chance of nitrosamines formation when the product is exposed to high temperatures (frying at $>100°C$). The whole issue of nitrite use in processed meat products and its safety has been reviewed by Cassens (1990).

Moisture is added to increase juiciness, compensate for cooking losses and, today as part of a system (i.e., with starch, gums) to achieve fat reduction. The amount of added moisture is regulated in many countries and, once exceeding a certain level in the finished product, it should be mentioned on the label (e.g., Turkey Ham with Natural Juices or with Added Water). Overall, moisture represents the largest portion in fresh and processed meats, ranging from 40–80%. Most of the moisture originates from the lean meat (e.g., fresh, skinless turkey breast meat has $\approx$ 75% moisture; Table 6.6). Processors add moisture to various products as part of the formulation (see recipes in this chapter), because many cooked products would have a dry mouth feel if only the original moisture, minus moisture evaporated during cooking (cook losses) is present in the final product. So, added moisture compensates for lost moisture during the heating process and allows the processor to improve yields. Moisture added also serves as a carrier for the non-meat ingredients in injected/marinated products and assures adequate distribution of the ingredients. In emulsion-type meat products, ice added during the chopping stage helps to maintain a low enough temperature to prevent an “emulsion breakdown” (see discussion on emulsion-type meat products at the end of the chapter).

The chemical and microbiological qualities of the water are very important issues. From a chemical standpoint, water contaminated with nitrate has been reported to cause pinking of oven roasted turkey breast and other white meat products. Low nitrite contamination (1–5 ppm) can result from a well located near fields fertilized with nitrates, especially after a heavy rainstorm (for more information on the pinking problem, see Chapter 13). Another consideration is the presence of high salt levels. High calcium and magnesium salts, also known as hard water, can cause problems within a plant’s piping system and also destabilize an emulsion-type meat product. From a microbiological standpoint, contaminated water can be a vehicle for transferring foodborne diseases (see Chapter 11). Therefore, continuous monitoring of water quality is very important for every plant.

Spices, seasonings and coloring agents are used to add new flavors and, in the case of some spices (e.g., paprika), to enhance color. (Note: in most countries, artificial food coloring is not permitted in meat products.) Several spices also possess antimicrobial and antioxidant properties (e.g., rosemary) and can be used to assist in shelf life extension and suppression of lipid oxidation.

Spices are derived from different parts of plant material:

- bulbs: garlic *(Allium sativum),* onion *(Allium cepa)*
- fruit: pepper *(Piper nigrum),* paprika *(Capsicum annuum)*
- leaves: sage *(Salvia officinalis),* thyme *(Thymus vulgaris)*
- roots: ginger *(Zingiber officinale)*
- bark: cinnamon *(Cinnamomum zeylanicum)*
- seeds: nutmeg *(Myristica fragrans),* mustard *(Brassica nigra)*
- flowers: clove *(Eugenia caryophyllata)*

When used in meat products, they can be added before or after drying (e.g., onion), whole or ground (e.g., mustard seeds) or as extracts (e.g., rosemary oleoresin). The main two forms are referred to as natural and extracts. Natural means that the whole or ground spice is used. In the case of mustard seeds, the decision is based on the desired appearance. In coarse-ground products, such as turkey kolbassa, a cross section of the seeds can enhance the appearance, while in a finely chopped hot dog, it will not be as attractive (see recipes for both products in this chapter). Natural spices are commonly used after they have been dried because, in this form, they are much easier to handle and store. All natural spices should be thoroughly cleaned in order to reduce/eliminate the microorganisms present; spices grow in or close to the ground and commonly carry a high bacteria load. Heat treatment is usually not the best approach because most of the flavor compounds are volatile and will be driven out by heat. Therefore, chemical sterilization (e.g., ethylene oxide; permitted in some but not all countries) or ionizing radiation are used—both considered cold processes where there is no temperature rise. Chemical sterilization possesses a potential risk of leaving some toxic residues, and therefore, in some countries, a large portion of spices is treated by irradiation. When irradiated spices are added to meat products, they usually only have to be identified by their name, without the word “irradiated” appearing on the package because of the low usage level. If the whole product is irradiated, the international logo for irradiated food (see Chapter 7) should appear on the package.

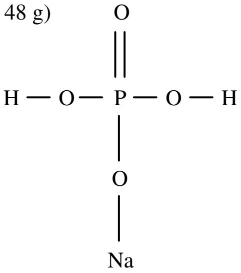
Spice extracts usually consist of essential oils extracted from the plant. The essential oils are obtained by pressing, distilling or solvent extraction. The oils can later be concentrated to obtain a more potent solution. The resulting oils are usually free of microorganisms because of the high distillation temperature or the nature of solvents used. Once added to a meat product, the extracts are invisible to the consumer. Comminuted products, such as bologna, have a homogeneous appearance, and adding visible particles of ground black pepper would not be acceptable to the consumer. Because the extracts are highly concentrated, they are commonly sprayed on a carrier such as dextrose or salt. This method helps assure good flavor distribution within the product (i.e., a minute amount of oil cannot be evenly distributed within a large batch of meat).

Another important consideration when using spices is standardizing the flavor strength. Because spices grow in different parts of the world, under different climate conditions, and are collected from different plants, large flavor variations can be expected. To overcome this problem, spice companies employ well-trained personnel to standardize flavor strength so that processors know exactly what they get and, thereby, avoid any surprises.

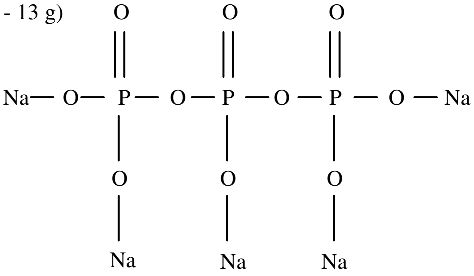
Flavor enhancers are chemical compounds that exert a unique property of working synergistically with meat flavor compounds in enhancing the meaty flavor. A few of those most commonly used are monosodium glutamate (MSG), 5′-ribonucleotides and hydrolyzed yeast proteins. The compounds contribute a delicious or umami taste to foods (meat, vegetables) when used at levels in excess of their independent detection threshold, and they enhance flavors at levels below that. It is important that food processors be aware of the fact that there is a certain (small) percentage of the population that is sensitive to MSG. Sensitive people will suffer from headaches and nausea, and therefore, MSG should be clearly marked on the label.

Phosphates are salts of phosphoric acid that can work together with sodium chloride to enhance muscle protein extraction and, hence, improve water-holding capacity and reduce cooking shrink (Figure 9.1). There are many types of phosphates available on the market. Examples of the commonly used polyphosphates and orthophosphate (i.e., a breakdown product of polyphosphates in meat) are shown in Figure 9.2. The most popular ones are the alkaline polyphosphates such as tripolyphosphate (TPP), which, according to some estimates, represents more than 50% of the phosphates used by the meat industry. Phosphate use is limited to 0.5% in countries such as the United States and Canada and totally prohibited for use in most meat products in countries such as Germany. This limit is mainly imposed to restrict water addition, however, a usage level above 0.5% can also cause off-flavor problems reported by consumers as metallic and soapy flavors.

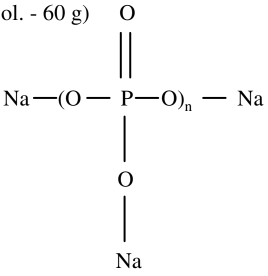
Figure 9.1 shows the beneficial effects of using 0.5% TPP, pyrophosphate and a blend called KENA, which contains over 50% TPP. The synergistic effect is clearly seen when TPP is used with 2–5% salt (i.e., the combined effect of 2% NaCl + 0.5% TPP is much greater than the simple additive effect of NaCl and TPP by themselves). The “salting out” effect, previously discussed, is clearly seen at a salt level >5%. Pyrophosphate has an even greater synergistic effect, when combined with NaCl, on reducing shrink losses; however, Sodium orthophosphate (pH - 4.6; sol. - 48 g)



Sodium tripolyphosphate (pH - 9.8; sol. - 13 g)



Sodium hexametaphosphate (pH - 6.8; sol. - 60 g)



Sodium acid pyrophosphate (pH - 4.2; sol. - 13 g)

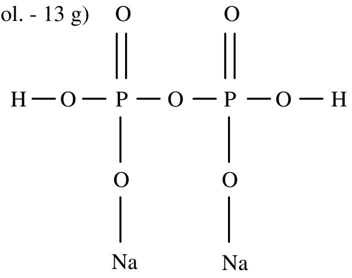


Figure 9.2. *The Chemical Structure of Some Phosphates Used in Meat Processing [pH in 1% Solution and Solubility (sol.)—g/100 g Saturated Solution at 25°C].*

pyrophosphates are not commonly used by themselves due to, among other factors, their effect on pH. Figure 9.1 also illustrates the point that not all polyphosphates act synergistically with salt to reduce shrink. Hexametaphosphate actually causes an increase in shrink during cooking. Therefore, it is very important that a processor know exactly what kind of single phosphate or blend he/she uses.

Most phosphates have been reported to improve the physical and sensory properties of meat products.

The four main contributions of phosphates are as follows:

- increase water-holding capacity due to protein extraction and shifting of the pH from the isoelectric point of the muscle's proteins
- assist in stabilizing meat emulsions due to the hydrophilic/hydrophobic structure of the molecule
- retard oxidation due to the chelating activity of phosphate (i.e., can bind iron and prevent it from acting as a pro-oxidant)
- enhance flavor

Phosphate contribution is the result of the three basic chemical functions they can perform in food: act as polyanions to increase ionic strength, control pH by buffering and sequester meat ions. The increase in WHC is claimed by some to be due to a nonspecific ionic-strength effect. An increase in net negative charges results in repulsion of the protein groups and an enlargement of the spaces available for water absorption within the muscle (see Chapter 14). Increasing ionic strength also increases the solubility of proteins, and this effect, as with the WHC, may be a nonspecific ionic-strength effect of phosphate. However, the effect of pyrophosphate on WHC seems to be greater than would be expected due to its ionic strength alone. A "specific" pyrophosphate effect was implied, where pyrophosphate dissociated actomyosin into actin and myosin (similar to adenosine triphosphate, ATP) in terms of its structure and ability to resolve the actomyosin complex.

Sweeteners can be added to meat products for a variety of reasons:

- to mask saltiness
- to add flavor
- to enhance browning (the Maillard reaction)
- to act as a substrate for fermentation

Sugars vary in their sweetness. Sucrose or cane sugar (disaccharide composed of glucose and fructose) is commonly used as the standard and is assigned a sweetness value of 100. In comparison, dextrose (monosaccharide of glucose monomers) is 74, fructose is 175, maltose (disaccharide of glucose + glucose) is 40, lactose (or milk sugar) is 16 and regular corn syrup solid is 37. So, the level of added sugar should be in proportion to its sweetness. If a carbohydrate source is added as a filler, it is usually an ingredient with a low sweetness value (see discussion below regarding fillers).

Sugars are also divided based on their being reducing or nonreducing. Reducing sugars contribute to the Maillard browning reaction when they combine with secondary amines and form a brown pigment (see Chapter 13). Adding a small amount of reducing sugar (e.g., dextrose, fructose, maltose) to a meat product can enhance surface browning. This is beneficial in smoked products where a nice brown color is desired. Reducing sugars are also added to fried products, such as turkey breakfast sausage, where a fairly fast brown color development during heating prevents the consumer from overcooking/frying the product.

Antioxidants are compounds capable of suppressing the lipid oxidation process. The process is driven by free radical formation and, once started, it accelerates quickly because one free radical is forming two, two are forming four, etc. Antioxidants can be of different types: free radical terminators, oxygen scavengers and chelating agents capable of tying up metal ions. There are certain restrictions on using synthetic antioxidants and some are not permitted for use in certain countries. Therefore, the industry has shown an interest in using natural antioxidants such as rosemary oleoresin. The most common antioxidants used by the food industry include the following:

- butylated hydroxy anisole (BHA)
- butylated hydroxy toluene (BHT)
- propyl gallate (PG)
- citric acid

BHA, BHT and PG are free radical terminators that have a cyclic carbon ring capable of accepting/tying a free radical molecule. They are fat soluble, and their usage level is usually limited to 200 ppm of the fat content. Citric acid is an oxygen scavenger, meaning it can tie up free oxygen. Figure 9.3 shows the beneficial effects of using BHA/BHT mixture (200 ppm) and a natural rosemary oleoresin on delaying lipid oxidation in a turkey sausage produced with 25% mechanically deboned meat. The latter meat is highly susceptible to oxidation (see Chapter 6). Both BHA/BHT and rosemary oleoresin were very effective in suppressing oxidation in the stored product. The spice mix used by itself also resulted in some antioxidant activity as compared to a control treatment (meat only). The figure also illustrates the effect of salt that can accelerate lipid oxidation due to the presence of a small amount of heavy metal (e.g., iron) contamination. The data is reported as the amounts of oxidation by a product (i.e., malonaldehyde is a breakdown product of oxidized fatty acids), which is commonly used in the literature to follow lipid oxidation. The publication also lists the amounts of other by-products (e.g., hexanal, heptanal, penanol; measured by gas chromatography) that actually contributed to the off-odors detected by a sensory panel.

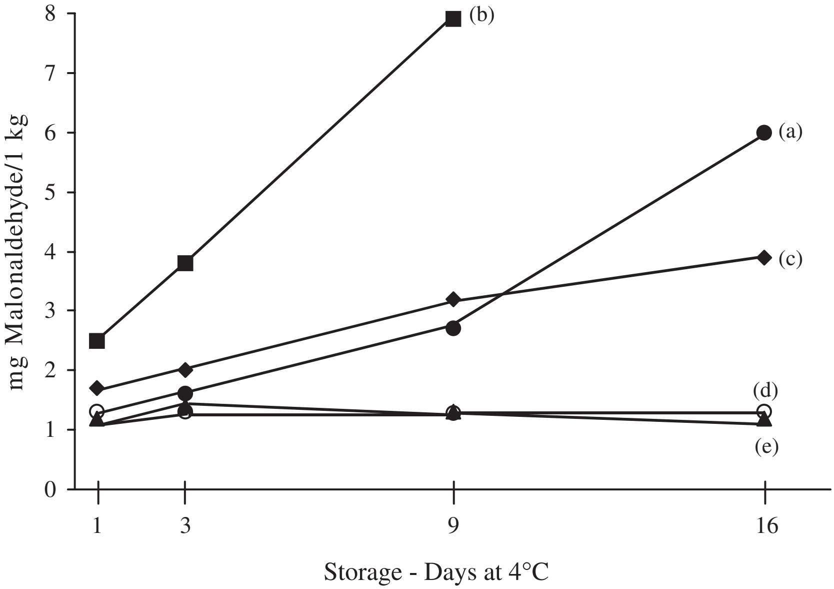


Figure 9.3. *Oxidation By-Product Values of Raw Turkey Sausage. Legends: (a) No Additives (●); (b) 1.7% Salt (■); (c) Spice Only (◆); (d) Spice + Rosemary (○); (e) Spice + BHA/BHT (▲). Adapted from Barbut et al. (1985).*

Mold inhibitors, such as potassium sorbate and sorbic acid, are used in dry and semidry sausage production to inhibit mold growth on the dry surface. Sorbate is applied by dipping or spraying the outside casings. Sorbate use is permitted for use as a mold inhibitor on sausages in countries such as the United States, but it is not permitted in Canada.

Starter culture lactic acid bacteria are added to fermented sausages such as salami and summer sausage. By fermenting added sugars, they produce lactic acid and reduce the pH. The most popular cultures include bacteria such as *Lactobacillus plantarum* and *Pediococcus acidilactici*. The inoculation levels usually reach 10^7 bacteria per gram, so they can dominate the fermentation from the very beginning of the process (see also Chapter 11).

Binders commonly consist of non-meat proteins used to do the following:

- increase water-holding capacity
- increase emulsification capacity
- reduce shrinkage during processing
- reduce formulation cost
- enhance flavor

Common binders used by the meat industry include the following:

- Nonfat dry milk—has about 35% protein (80% is casein) and about 50% lactose.

- Calcium-reduced nonfat dry milk—is used for finely chopped/emulsified products because it does not contain high levels of calcium, which is detrimental to emulsion stability.
- Soy protein—is used as a binder in meat patties, meat loaves and sausages. It is limited to 2% soy protein isolate or 3.5% soy flour in U.S. products. If a higher level is used, it should be mentioned with the product name or be labeled "imitation." The various soy protein forms include the following:
    - ► Soy flour—fine particles with 40–60% protein
    - ► Soy grits—coarse particles with 40–60% protein (Both flour and grits have a distinct flavor, beany, at a high concentration.)
    - ► Textured soy protein—cooked and extruded particles sized to order; can be produced with flavorings and color added
    - ► Soy protein concentrates—with 70% protein and bland flavor (can be texturized)
    - ► Soy protein isolate—with 90% protein and bland flavor, good water and fat binding

Fillers are ingredients with high complex sugar content (e.g., starch) and low protein concentration. Therefore, they can bind water but do not contribute much to emulsification. The main groups of fillers used by the meat industry include cereal flours (wheat, corn, rice) and corn syrup solids. The different cereal flours can be added as straight flours or extruded/texturized particles. They are also used in the coating of battered and breaded products (see Chapter 10).

Hydrocolloid gums are special compounds that can form a gel matrix at low concentration (e.g., 1% and hold 99% water). They are added to processed meat products at a low concentration to bind added moisture (see carrageenan use in recipe for Turkey Pastrami in this chapter) and enhance texture. Some are derived from seaweeds, while others are the result of microbial fermentation or are extracted from seeds. Examples of common gums used by the meat industry include the following:

- Carrageenan—is extracted from Irish moss. It is composed of monomers of sulfated galactose and anhydro-D-galactose. The gum is a complex mixture of five distinct polymers; kappa and iota are the most important in meat product formulations. The type of gel formed depends on the dominant polymer in the mixture and the cation used to induce gelation. The gum is very effective in binding moisture and is added to products such as oven roasted turkey breast and pastrami.
- Xanthan gum—is produced by microbial biosynthesis and is an extracellular polysaccharide. It is composed of cellulose chains with attached oligosaccharide groups. Low xanthan concentrations produce a highly viscous solution. Together with locust bean gum, xanthan produces a thermoreversible gel.

- Alginate—is extracted from brown algae and is composed of manmuronic and guluronic acid monomers. It gels at room temperature in the presence of a small amount of calcium. In the meat industry, it is used for binding small meat particles and also to enhance texture. There is a patented process that includes alginate to manufacture restructured meat products (i.e., provide binding of the small meat chunks and hold the product together prior to cooking).

Curing accelerators are used at very low concentrations (usually 500–1000 ppm) to promote reducing conditions within a nitrite-added meat system. They accelerate reduction of metmyoglobin to myoglobin and of nitrite to nitric oxide. This, in turn, shortens curing time, which is especially important in a continuous sausage manufacturing line. Conversion of NO_2 to NO is faster and more complete. In some cases, such as bacon manufacturing, some countries (e.g., the United States) require that a curing accelerator be added because high frying temperatures can increase nitrosoamine formation. The two commonly used compounds are sodium ascorbate or ascorbic acid and sodium erythorbate or erythorbic acid.

Acidulants are used to reduce the pH of a meat product and produce a fermented-like meat product. An example is glucono delta lactone (GDL), which was introduced during the 1960s to give a more rapid and improved color development to cooked comminuted meat products. Although introduced to accelerate raw meat processing operations, GDL has been successfully used in the production of semidry and dry meat products. During heat treatment, or hydrolysis, GDL yields gluconic acid that effectively reduces the pH of the meat batter and also provides a distinct flavor.

Smoke and smoke flavorings are added for the following reasons:

- flavor development
- to add variety (new products)
- preservation
- color development (Maillard reaction)
- protection from oxidation

In the past, smoking meat over an open fire was used as an effective means of preservation, because the product, exposed to high temperatures for extended periods of time, was also dried. Today, smoking is commonly employed for a short period of time, mainly to add flavor to the product. The main compounds in natural smoke include the following:

- phenols—important in color and flavor development, preservation and retarding oxidation
- organic acids—important in preservation and coagulation of surface proteins (i.e., assist in casings peeling)
- carbonyls—contribute to flavor and color development

- polycyclic hydrocarbons—created when a high burning temperature is employed (Some of the compounds, such as benzopyrene, are potentially carcinogenic).

Overall, natural smoke is a very complex mixture of chemical compounds. There have been over 300 compounds isolated from wood smoke (Maga, 1989). Smoke can be applied as traditional smoke generated from the burning of hardwood chips or as a liquid smoke solution. Combustion of hardwood (e.g., cherry, maple) is commonly done in a special generator outside the smokehouse. The moist sawdust is slowly burned, and the smoke is carried by a fan system into the house. Liquid smoke is a newer product prepared in special plants by extracting the different smoke compounds from burning wood. This is usually achieved by letting the smoke rise inside a chimney with a counterflow of water droplets. The smoke compounds can later be concentrated, and the preparation is applied to meat products as a spray, atomized mist or dip. In addition, it can also be added directly to the raw product, provided the pH is adjusted.

Casings

Most sausages manufactured by the meat industry are stuffed into casings. The raw meat batter is usually a viscous material that can be pumped and stuffed into casings of different sizes. During cooking, the meat proteins form a heat-stable gel (see section on gelation in this chapter). Later, the firm product can be removed from the casings at the processing plant (e.g., hot dogs), at the store or by the consumer prior to slicing/consumption (e.g., salami, kolbassa). Edible casings (i.e., natural or manufactured collagen) can be left on the product and consumed with no problem (e.g., safety, digestibility) in products such as turkey breakfast sausage.

Humans have been using natural casings derived from the gastrointestinal tracts of sheep, hogs, cattle, etc., for thousands of years. During the past century, there has been a rapid development of manufacturing new materials, including casings and extruded food packaging materials. Today, there are hundreds of different types of casings on the market. They can be divided into a few major groups:

(*1*) Natural casings are derived from digestive tracts of sheep, cattle and swine. The casings have to be thoroughly cleaned and are later stored in a salt solution. They are permeable to water and smoke, and can shrink with the product because they adhere to the surface. This is a very important feature in dry sausage manufacturing, where the product loses water during the drying operation, and loose casings will make the product unsalable. Quite a few of the natural casings are digestible and do not have to be peeled off the product prior to consumption. Generally speaking, they are expensive and considered for use in special products to provide an "old-fashioned" look.

(*2*) Manufactured collagen casings are made from regenerated collagen extracted from skins and hides of various red meat animals. They are usually edible (depending on the thickness) and do not have to be removed prior to consumption. They are uniform and do not show size variations or weak spots like the natural casings. Manufactured casings are easier to work with compared to natural casings (e.g. less occasional rupturing), less expensive to buy and require less labor. Another advantage is that they are stronger than natural casings. Their size uniformity also makes them easy to use for portion control, where a certain number of links can be made to a certain weight. Because they are manufactured, their microbial load is lower than natural casings (e.g., the process of extracting the collagen requires high temperatures and extreme pH conditions). The casings are permeable to water and smoke, similar to natural casings and can shrink with the product.

(*3*) Manufactured cellulose casings are made from wood pulp or cotton linters and can be made into various sizes (e.g., 1.5–15 cm in diameter). Some are very strong and lend themselves to highly automated equipment. Because they are manufactured, they are uniform and again can be used for portion control. They are nonedible and have to be peeled off prior to consumption. They are water and smoke permeable. Cellulose casings can come in different colors and shades, and advertising material can be printed on them. They come with a very low microbial load, which is advantageous for clean manufacturing. In some applications, the inside of the casing is coated with protein to make it better adhere to the product. Some can be coated to make them moisture proof.

(*4*) Manufactured plastic casings are used for water/steam cooked sausages because they are impermeable to water. They are also impermeable to smoke. Extruded plastic casings are very strong and uniform, and therefore, can be used for large diameter products. The plastic casings also offer protection against oxidation, because they are usually impermeable to oxygen. Materials such as polyethylene, nylon and polypropylene are used as a single layer or as a combination of different layers. They are all extruded, so usually there is no seam (i.e., weak point) in the casing. Some are available with a UV barrier, so color fading (see Chapter 13) is not a problem. They can be colored, and material can be printed on them.

(*5*) Metal or plastic molds are used for forming loaf-type items to provide the product with a certain shape. In some cases, a cellulose/polyethylene casing is used to stuff the product before it is placed in a metal press (see recipe for Turkey Ham in this chapter), so it is easier to remove the cooked product from the mold. In addition, plastic casings can provide a barrier against recontamination of the cooked product. The resulting product has the shape of the mold (e.g., 4 × 6 inches for the Turkey Ham product described in this chapter) which also lends itself to easy portion control.

(*6*) Retortable pouches/cans are used for meat products to be sterilized at high temperatures. Meat loaf-type products and chicken soup/stew are commonly packaged in such a way and then retorted at a temperature of about 121°C (see Chapter 7 for information about canning).

(*7*) Combination casings are manufactured casings made from two or more materials, such as collagen reinforced with a cotton mesh or cotton fibers coated with plastic. By combining materials, one can have the advantage of both (e.g., extra strength of plastic with the smoke permeability of cellulose).

RECIPES

Recipes of popular poultry products are provided below. The formulations have been used for commercial production. However, they are only guidelines and should be used as such. Because government regulations vary among countries (e.g., nitrite, phosphate levels), further examination of local regulations is advised.

All the recipes are courtesy of Hermann Laue Spice company, Uxbridge, ON, Canada.

Flavored Turkey Roast (30% pump)

Ingredients

Meat: 100.0 kg boneless, skinless turkey breast
Brine: 30.0 kg

The brine is made by mixing:

21.8 kg cold water
3.8 kg ice flakes
4.0 kg brine and cure unit (salt, sugar, phosphate, erythorbate, nitrite)
0.4 kg roast seasonings (natural roast flavor, spices)

Spice rub: 6 g roast-flavored rub mixed with 18 ml of water, per 1 kg of tumbled roast.

Processing

Inject the turkey breast meat with 30% brine.

Vacuum tumble for 4 hours at 12–15 rpm; start immediately after injecting. Rest overnight and tumble for 1½ hours at 12–15 rpm.

Combine two turkey breasts (thick end over thin end) and wrap with collagen film before stuffing into a ham net #22-3 (i.e., a net with 22 squares around the circumference, made up of three stitches between squares). Clip both ends of the net.

Mix five parts of roast-flavored rub together with three parts of water until a thick paste has been formed, and rub the roasts evenly.

Place roasts on smoke screens, place in an oven and cook.

Dry cook at 90°C for 1 hour or until the surface is completely dry.

Steam cook at 78°C to an internal temperature of 71°C.

Shower with cold water to cool down quickly

White Turkey Roast (50% pump)

Ingredients

Meat: 100.0 kg boneless skinless turkey breast
Brine: 50.0 kg

The brine is made by mixing:

34.9 kg	cold water
8.8 kg	ice flakes
5.0 kg	turkey roast brine unit (salt, sugar, phosphate)
1.3 kg	spice unit (soy protein isolate, sugar, spice extracts)

Processing

Inject turkey breast meat with 50% brine.

Vacuum tumble at 12–15 rpm for 3–4 hours; start immediately after injecting. Rest overnight and tumble for 1–2 hours under vacuum (in order to obtain maximum yield, use refrigerated environment, and total tumble plus rest time should be 12–14 hours).

Wrap breast meat in edible collagen film and place in ham net #22-3. The film will allow easy removal of the netting after cooking.

Steam cook the roasts at 78°C to an internal temperature of 71°C.

Shower with cold water to cool quickly.

Smoked Turkey Roast

Ingredients

Similar to previously described White Turkey Roast.

Processing

Similar to injection and stuffing of White Turkey Roast.

Heating and Smoking

Dry cook at 65°C for 45–60 minutes.
Hot smoke at 65°C for 1½ hours or to the desired color.
Steam cook at 78°C to an internal temperature of 71°C.
Shower with cold water to cool quickly.

Turkey Pastrami

Ingredients

Meat: 65.0 kg turkey thighs, ground through a 25 mm plate
6.4 kg dark turkey trim, ground through a 3 mm plate
Brine: 28.6 kg

The brine is made by mixing:

20.0 kg cold water
1.8 kg ice flakes
6.8 kg pastrami pickle and cure unit (salt, sugar, carrageenan, phosphate, spices, erythorbate, nitrite)

Processing

Tumble all ground turkey meat in a vacuum tumbler. Completely dissolve the pastrami pickle and cure unit in the cold water before adding the ice. Add the brine to the ground meat in the tumbler.

Vacuum tumble for 6 hours at 10–12 rpm, rest overnight and tumble for additional 2 hours.

Fill the meat batter into loaf pans approximately 10–12 cm wide and 5–6 cm high.

Sprinkle a pastrami rub spice mix on top for a nice presentation (optional).

Place the loaf pans on smoke screens, allowing sufficient space for a free airflow.

Bake at 80°C dry heat for 45 minutes or until the top surface feels dry.

Steam cook at 78°C to an internal temperature of 70°C.

Bake at 80°C dry heat to an internal temperature of 71°C.

Air cool in a refrigerator overnight.

Remove product from pans and place on smoke screens.

Hot smoke at 65°C, 40% relative humidity until the desired color is reached.

Store under refrigeration overnight prior to vacuum packing. Note: the product can also be prepared in casings.

Smoked Turkey Sausage

Ingredients

Emulsion part (60 kg):	42.0 kg turkey thigh meat (ground 3 mm) 8.0 kg turkey skin (frozen, ground 3 mm) 10.0 kg ice
Coarse insert (40 kg):	34.0 kg turkey thighs (ground 5 mm) 6.0 kg cold water
Spice/ingredients mix:	3 kg seasoned binder (salt, potato starch, dextrose, spices, erythorbate) 1 kg brown sugar 0.3 kg curing salt 0.3 kg phosphate 0.2 kg garlic powder 0.1 kg black pepper (fine grind)

Processing

Mix the coarse ground meat, one day prior to processing, together with all its water and 40% of the spice/ingredient mix, until a good bind develops. Store the meat under refrigeration overnight.

Chop the ground meat and skin, intended for the emulsion part, while adding the rest of the spice/ingredient mix. Chop for a few revolutions at the slow speed before adding about 1/3 of the ice. Continue cutting at fast speed to a temperature of 12°C, add the rest of the ice and proceed cutting to a final temperature of 8°C.

Add the preseasoned coarse insert and mix well before cutting at slow speed to the desired size.

Stuff the meat into hog casings (29/32 caliber) or any other smoked sausage casings.

Dry in a smokehouse at 55°C for 15 minutes.

Hot smoke at 60°C, 25–30% relative humidity for 30 minutes or until the desired color is reached.

Steam cook at 78°C to an internal temperature of 71°C.

Shower with cold water for fast cooling.

Turkey Kolbassa

Ingredients

Coarse insert (50 kg):	42.0 kg turkey thighs (ground 12 mm) 8.0 kg cold water
Fine part (50 kg):	42.0 kg dark turkey trim (ground 3 mm) 8.0 kg cold water
Spice/ingredients mix:	4.35 kg kolbassa seasoning and binder unit (salt, dextrose, phosphate, spices, erythorbate, nitrite)

Processing

Grind the meat intended for the coarse insert through a 12 mm plate, one day prior to processing.

Vacuum tumble for 2 hours together with one-half of the spice/ingredient mix and water. Store in refrigerator overnight.

Grind the fine part portion through a 3 mm plate and mix with the other half of the spice/ingredient mix and water until a good bind has developed.

Add the pre-tumbled coarse insert, and mix to obtain an even distribution and a good bind.

Stuff into ring casings (e.g., 47 mm caliber) and form individual rings or coils; to produce deli kolbassa for slicing, stuff into fibrous casings (e.g., 90 or 105 mm diameter).

Hot smoke at 65°C until a desired color is reached.

Steam cook at 78°C to an internal temperature of 71°C.

Shower with cold water and refrigerate.

Turkey Hot Dogs/Bologna

Ingredients

Meat: 86.0 kg mechanically deboned chicken meat
Ice: 14.0 kg

Spices and Additives

Binder unit 8.70 kg (salt, soy/whey proteins, spices, erythorbate)
Curing salt 0.3 kg
Phosphate 0.3 kg

Processing

Chop the slightly frozen meat with about 5 kg of flaked ice in a bowl chopper for a few revolutions.

Add the binder unit, salt and phosphate and chop at the high speed setting while adding the rest of the ice until the temperature reaches 8–10°C.

Remove the batter from the chopper.

Stuff into easy-peel hot dog casings and link to desired size.

Place the product on a smokehouse tree.

Smoke and Cook

Dry cook for 5 minutes or as required at 55°C

Hot smoke at 55°C and 25% relative humidity for 20–30 minutes.

Steam cook at 75°C to an internal temperature of 71°C.

Shower with cold water for 10 minutes.

Refrigerate overnight prior to peeling the casings.

Note: for bologna, use the same formulation and procedure, and then stuff into large-diameter cellulose or fibrous casings. The heat process should be lengthened to achieve a 71°C internal temperature.

Turkey Ham (4 × 6)

Ingredients

Meat: 100 kg boneless lean turkey thigh meat
Brine: 40 kg

The brine is made by mixing:

30 kg cold water
4.5 kg ice
5.5 kg brine and cure unit (salt, soy/whey proteins, phosphate, spices, erythorbate, nitrite)

Processing

Lacerate the turkey thigh meat (especially from the skin side) to increase the surface area of the lean meat portion.

Tumble the meat with the brine in a well-chilled vacuum tumbler for 6 hours at 12–15 rpm. Rest overnight and tumble for 1.5 hours the next day.

Stuff the meat into cook-in-bags (also referred to as “cook and ship bags”).

Place hams into 4 × 6 inch ham molds and press firmly.

Cook in a smokehouse using steam at a temperature of 78°C, until reaching an internal temperature of 71°C.

Shower with cold water to chill quickly prior to transferring to a refrigerator.

Hot Habanero Turkey Sticks

Ingredients

Meat: 40.0 kg turkey drumstick meat, ground 3 mm
10.0 kg turkey fat, frozen, ground 5 mm
50.0 kg turkey thigh, ground 5 mm
Spices and cure: 5.55 kg seasoning and cure mix (salt, dextrose, paprika, spices, erythorbate, nitrite)

Processing

Mix all of the ground meat and fat together with the seasoning and cure until a good bind has developed.

Stuff the batter into natural casings or collagen casings (caliber 15–20 mm).

Process the product in a smokehouse:

- dry heat at 55°C for 2 hours
- dry heat at 60°C for 1 hour
- dry heat at 65°C for 1 hour
- dry heat at 72°C for 1 hour or until the desired dryness is reached

If desired, hot smoke can be applied during the second drying cycle.

Product is to be air cooled only.

Honey Garlic Marinated Chicken Wings

Ingredients

Meat: 90.0 kg chicken wings
Water: 10.0 kg (cold)
Spice: 5.5 kg honey garlic marinade (sugar, salt, garlic, natural honey flavor, vinegar, spices)

Processing

Dissolve the spice unit in the cold water.

Vacuum tumble the well-chilled chicken wings together with the liquid marinade; use a slow speed for 30–45 minutes.

Remove the marinated chicken wings from the tumbler and pack in vacuum bags or individually quick freeze (IQF).

Keep product refrigerated or frozen prior to shipping.

Lemon Ginger Chicken Drum Sticks

Ingredients

Meat: 85.0 kg chicken drumsticks
Water: 15.0 kg (cold)
Spice: 6.5 kg lemon ginger marinade (salt, sugar, lemon juice, spices)

Processing

Mix the spices together with the cold water.

Vacuum tumble the well-chilled chicken drumsticks together with the liquid marinade; use a slow speed for 30–45 minutes.

Remove the marinated chicken drumsticks from the tumbler and pack in plastic bags or immediately freeze.

Note: other variations, such as Hot Buffalo Chicken Wings can also be made the same way, but with a different spice mix.

Keep product refrigerated or frozen prior to shipping.

Chicken Fajita

Ingredients

Meat: 82.0 kg chicken breast fillets or breast strips
14.8 kg cold water
Spice: 3.2 kg chicken fajita seasoning (salt, dextrose, soy sauce powder, phosphate, garlic powder, spices)

Processing

Completely dissolve the fajita seasoning in the cold water.

Vacuum tumble the chicken meat and seasoning solution for 40–50 minutes at 8–10 rpm.

The marinated chicken strips can then be individually frozen and packed or put onto a skewer and frozen.

Prior to serving, pan fry together with red, yellow and green bell pepper strips and fresh or frozen diced onions.

Serve on pita bread or in taco shells; a sauce can be added if desired.

Jellied Turkey Roll

Ingredients

Meat: 45 kg white turkey roast (see first recipe)
Vegetables: 15 kg broccoli heads and/or canned mushrooms
Gelatin: 40 kg gelatin solution (7 kg seasoned gelatin powder plus water)

Processing

Dice the turkey roast into 1 × 1 × 1 cm cubes.

Rinse the broccoli (and/or mushrooms) with hot water and mix with the diced meat.

Completely dissolve the dry gelatin powder in hot water (≥80°C). You can add a little bit of oil to the hot water to avoid foaming.

Fill clear plastic casings (e.g., 12 cm diameter) with the diced meat and vegetable mix.

Add the proper amount of gelatin solution into the casings and remove all air bubbles prior to clipping.

Cool in a cold water bath.

Turkey Chili Con Carne

Ingredients

Meat: 31.25 kg turkey thigh meat
Vegetables: 25.00 kg red kidney beans (canned)
28.15 kg chopped tomatoes (canned)
7.80 kg diced onions (frozen)
7.80 kg hot water
Spice: 2.62 kg chili seasoning mix (sugar, salt, paprika, garlic powder, spice)

Processing

Grind turkey thigh meat through a 3 mm plate.

Mix ground meat together with the chili seasoning mix and hot water.

Cook in a steam kettle over medium/high heat until meat is well done.

Add all of the canned and frozen vegetables, bring to a boil and simmer over medium heat for 10–15 min.

Cool completely prior to packing.

All recipes are courtesy of Hermann Laue Spice Company, Uxbridge, ON, Canada.

Recipes for Chicken Nuggets and Chicken Cordon Bleu appear in Chapter 10, Tables 10.1 and 10.3, respectively.

PROTEIN GELATION

The binding of meat pieces together during cooking involves extensive protein-protein interactions as a result of heat denaturation. Muscle-protein gelation is essential to the formation of a desirable meat product texture. Furthermore, the degree of firmness, springiness and cohesiveness of the product is critical in manufacturing an acceptable product. Instrumental texture evaluations of fully cooked products (i.e., shear, compression, and extension tests; see Chapter 14) are by far the most popular methods currently used to quantify the effect of various treatments and additives. Studying the textural changes in a raw meat system during the cooking process and correlating the data with molecular changes represent a challenge to the food technologist. Recent studies involving continuous monitoring of the rheological changes taking place during gelation have been proven useful in studying the molecular changes within meat and other protein systems (Smyth et al., 1999; Marangoni et al., 2000). This approach became more feasible within the last few years with the introduction of inexpensive programmable thermal control. Prior to the development of scanning rigidity monitors, samples had to be changed for each temperature point, resulting in time being a continuous independent variable. One of the first models of a "batch-type" thermal scanning rigidity monitor (TSRM) apparatus was developed by Yasui et al. (1980); results are presented later in the chapter.

The main proteins responsible for meat product binding are the myofibrillar salt-soluble proteins, of which myosin and actin are the most important. The binding characteristics of gels prepared from isolated myofibrillar proteins provided some basic understanding of the gelation process. Removing various myofibril components, from gels or actual sausage batters, by specific extraction, indicated that myosin determines the binding quality, and that binding strength bears a close relationship to the amount of myosin or actomyosin liberated from the myofibrils. Some reports have indicated that actin by itself does not exhibit any binding (Figure 9.4), whereas others demonstrated actin gel formation under certain conditions. However, in the presence of myosin, a synergistic effect between actin and myosin is observed (Figure

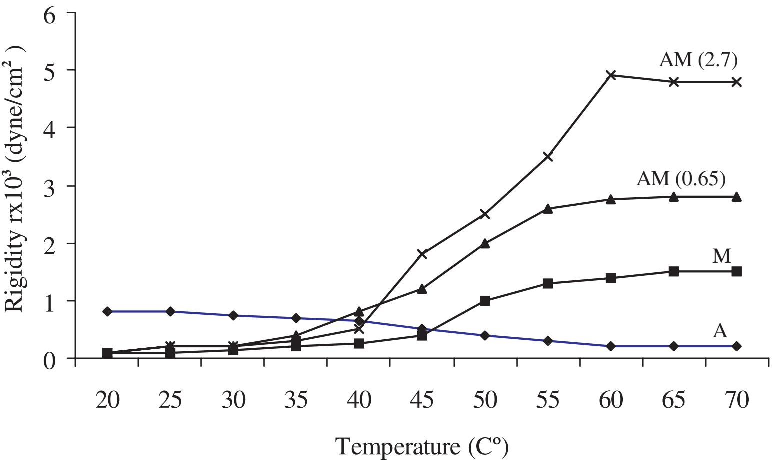


Figure 9.4. *Changes in Heat-Induced Gel Strength of Actomyosins that Were Reconstituted at Different Myosin-to-Actin Ratios. The Protein Samples (5 mg/ml) Were Dissolved in a 0.6 M KCl Solution Containing 20 mM Phosphate Buffer, pH 6, and were Incubated for 20 Minutes at Temperatures Varying from 20–70°C. Gel Strength Was Measured at Each Temperature. M, Myosin Alone; A, Actin Alone; AM, Actomyosin. The Figures in Parenthesis Indicate the Mole Ratio for Myosin-to-Actin Ratio in Respective Systems. Adapted from Yasui et al. (1980).*

9.4). This is because actin in the presence of other cross-linking proteins can enhance gel structure. The relationship between myosin and actin concentration on gel rigidity is demonstrated in the figure. Maximum rigidity was obtained when the myosin-to-actin mole ratio was 2.7, which corresponds to a weight ratio of myosin to actin of about 15:1. Increasing the portion of myosin beyond this point caused a decrease in gel strength. The authors suggested that the synergistic effect is either ionic strength dependent or is determined by the state of myosin per se at different ionic conditions. It can also be observed that, at temperatures below 40°C, actin exhibits some resistance, probably due to its thixotropic nature. However, upon heating, the gel collapsed into a compact string or bead-like structure, as was shown by scanning electron microscopy (SEM; pictures not shown here). Isolated myosin fragments were shown to affect gel characteristics differently. Intact myosin monomers produced the strongest gel, followed by myosin rods and by the S-1 fragment. The latter produced a gel that had poor water-retaining ability. These differences were also studied by SEM, where the myosin rods produced and extended the three-dimensional network system, and the S-1 fragment formed a bead-like aggregation upon heating. Combining myosin rods and the S-1 fragments did not result in the high gel strength observed for the intact myosin molecules. This indicates that, once cleaved, the disintegrated myosin did not have the same characteristics.

Salt concentration plays an important role in the amount of extracted protein and later binding. Reducing the salt level from 2.5–1.5% in commercial-type poultry meat batters (14% protein and 18% fat) resulted in a substantially lower final rigidity value of 4.9 vs. 12.2 kPa, respectively (Figure 9.5). Differences were also observed in the development of the modulus of rigidity (*G*) after the initial coagulation started at around 55°C. In both batters, a small but linear increase was observed up to 55°C, indicating that a protein matrix was continuously developing. When the temperature reached the myosin denaturation zone at around 55°C, a rapid increase in *G* was observed. However, when temperature reached the collagen and sarcoplasmic protein coagulation zone at around 63°C, a sharp decline in the 1.5% NaCl treatment's curve was observed, whereas a steady increase of the 2.5% NaCl treatment could be seen. The sharp rigidity decline might have indicated a structural breakdown in the reduced salt batter. The general gelation pattern for the 2.5% NaCl, reported in this study, was similar to the one reported by Montejano et al. (1984) for hand deboned turkey meat containing 2.5% NaCl. The rapid, steady increase in *G* from 56–70°C (Figure 9.5) indicated the formation of stable, stiff and

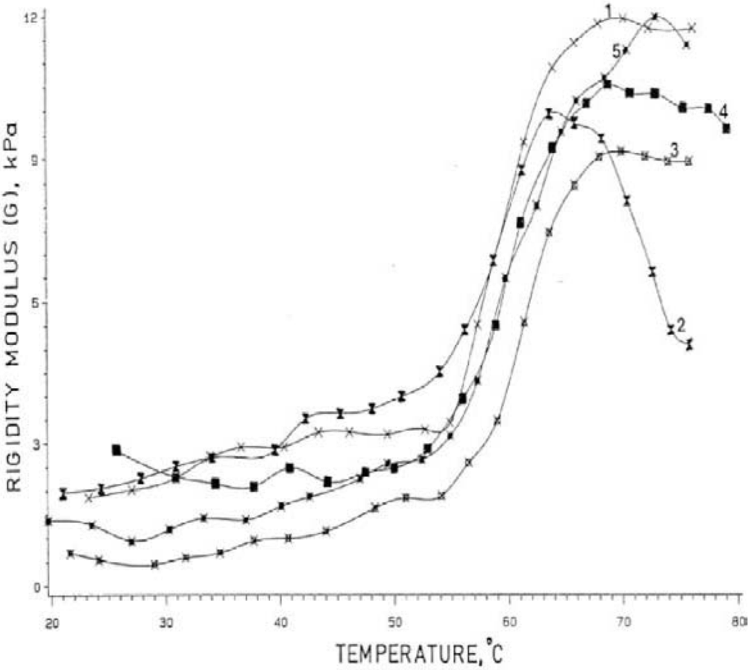


Figure 9.5. *Shear-Rigidity Modulus Profile of Reduced-Salt Poultry Meat Batters Containing Various Phosphates during Heating. 1 = 2.5% NaCl; 2 = 1.5% NaCl; 3 = 1.5% NaCl + 0.5% TPP; 4 = 1.5% NaCl + 0.5% HMP; 5 = 1.5% NaCl + 0.5% SAPP. From Barbut and Mittal (1989). With Permission.*

elastic matrix structure typical of heat-induced protein gels. With a further increase in temperature, there was no increase in *G* value up to 80°C. When three polyphosphates were added to the reduced-salt (1.5% NaCl) meat formulation, structure breakdown in the 63°C zone was eliminated, and differences in the gelation patterns were observed. The addition of 0.5% SAPP to the 1.5% NaCl batter resulted in the closest match to the rigidity modulus development pattern seen in the 2.5% NaCl treatment. It is interesting to note that, in another study, a taste panel also rated reduced-salt poultry frankfurters containing SAPP as most closely matching the texture of frankfurters containing 2.5% NaCl. The curve of the TPP treatment (Figure 9.5) indicated that structure formation followed the pattern of the 1.5% NaCl treatment up to 64°C, but unlike the 1.5% NaCl, it did not break down and stayed at a constant value ($G = 8.9$) up to 80°C. Addition of SAPP and HMP resulted in further increases of the *G* values as temperature was raised above 64°C. Evidently, the change from a viscous to an elastic structure in a meat batter happens almost instantaneously; additional heating further increases the rigidity modulus but only up to a certain point.

The pH of the meat also affects the gel, and certain pH values can prevent gel formation. Xiong and Brekke (1991) indicated that the optimum pH for gelation of chicken muscle in 0.6 M NaCl (or KCL) was about 6.0 for breast myofibrils and 5.5 for leg myofibrils. Figure 9.6 shows the effect of pH on the gelation of 3% salt-soluble proteins (SSP) extracted from chicken breast meat heated from 30–80°C. The complex modulus (G^*) used by the authors is proportional to the total amount of force required to deform a sample and is similar to the rigidity moduli reported by other researchers (Yasui et al., 1980). No major G^* transitions were observed, at pH 4.5, when SSP solutions were heated. This was because the proteins coagulated at this low pH and did not form a gel network. This is typical of protein systems at pH close to their isoelectric point (i.e., the net charge on the proteins is near zero). The isoelectric point of actomyosin is about 5.0, and at this point, an electrostatic attraction among the molecules can be seen. Electrostatic attraction minimizes protein unfolding, during heating, and prevents gel formation. At pH 5.5, 6.5 and 7.5, the G^* increased after the first transition at 35–47°C. It then reached a peak, decreased on further rise in temperature to the third transition around 54–60°C and then increased again until 80°C. The first transition, which led to the development of gel some elasticity, was attributed to unfolding in the tail portion of the myosin molecule. The G^* values at the end of cooking were significantly ($P < .05$) higher at pH 5.5 and 6.5 than at pH 4.5 and 7.5. The authors indicated that the thermal transitions graphed as differential plots of the complex modulus against temperature (dG^*/dT vs. T) were pH-dependent throughout the heating process (data not shown here). The differential plots illustrated the rate of change in G^* during heating, which could provide more

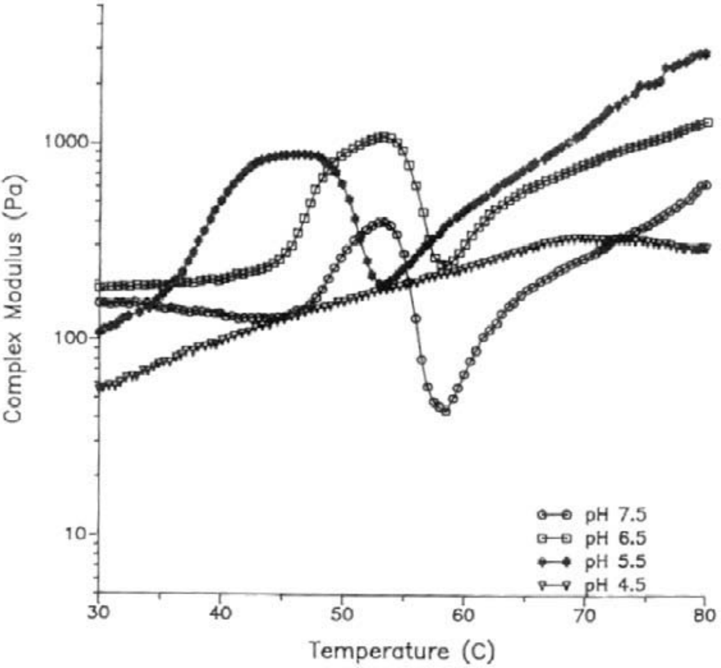


Figure 9.6. *Rheogram of the Complex Moduli (G*) of 3% Chicken Salt-Soluble Proteins at Different pH Heated at 1°C/min, 0.6 M NaCl. From Wang et al. (1990). With Permission.*

information on how pH affects protein conformational changes during sol-to-gel transition. No rate changes were observed for the SSP kept at pH 4.5 during the heating process. The first transition of the pH 6.5 and 7.5 treatments occurred above 45°C. It was found that at pH 5.5, even the third transition (the development of a shoulder) occurred before any changes were observed at the higher pH treatments. However, further transitions at pH 5.5 were similar to the higher pH treatments; temperature differences between the first and sixth transition were 18°C, 14°C and 12°C for pH 5.5, 6.5 and 7.5, respectively. Overall, the transition temperatures were almost identical at pH 6.5 and 7.5. A change in pH from 6.5 to 7.5 did not affect the rheological transitions, suggesting similar changes in protein conformation occurring during the gelation process. These results further stress that pH influences the unfolding and aggregation of protein molecules during heating and results in different gel properties (Smyth et al., 1999). Therefore, the pH of any meat source should be monitored and/or adjusted to obtain consistent product quality. Overall, the texture of meat products might be improved by adjusting the pH of the formulation.

COMMINUTED MEAT BATTERS (MEAT "EMULSIONS")

Finely comminuted meat products, sometimes referred to as meat emulsions, such as bologna and frankfurters, are composed of water, protein, fat and salt. These ingredients are comminuted either in a bowl chopper or an emulsion mill (see Chapter 8) in order to reduce the fat particle size and to obtain a homogeneous mass. The overall description of an emulsion is a mixture of two. However, it should be noted that meat products do not fall into the definition of a true emulsion, because, among other things, fat particle size can be >20 µm. The challenge to the meat processor is to produce a stable meat product that can undergo the cooking process without fat and water separation (Acton et al., 1983; Barbut, 1999). Products in this category are produced from different meats and non-meat ingredients (e.g., soy, whey, starch) all around the world. It is estimated that in North America, their market share is over 30% of further processed meats. Producing high quality comminuted products is an ongoing challenge to the processor dealing with a large selection of raw materials at prices fluctuating on a daily basis. The comminution process is designed to reduce the lean meat and fat particle size. This helps to better extract the salt-soluble proteins and reduce the tendency of the fat particles to separate; the type of meat and fat has a significant effect on the chopping procedure as well as on the quality of the final product.

An understanding of the mechanism(s) responsible for stabilizing/binding the fat within the product is important to the meat processor because most comminuted products contain 20–35% fat which is held by the 10–15% protein present in the product. In addition, the proteins are responsible for retaining the water (usually 50–60% of the formulation). From a practical standpoint, one of the major reasons for studying meat batter stabilization is the fact that during chopping, the processor cannot see/detect any warning signs indicating a later "emulsion breakdown" (a term referring to fat separation during cooking).

The main reasons for investigating the mechanism(s) affecting meat batter stability can be summarized as follows:

- Finely comminuted meat products represent a large segment of the processed meat market.
- "Emulsion breakdown" can be very costly, especially in high-volume processing plants.
- An understanding of the relationship between meat batter stability and processing equipment can assist the processor in making a more educated choice in selecting the best chopping/emulsifying equipment available on the market, as well as purchasing the best non-meat binders for a specific product (i.e., not an easy task with so many binders currently available on the market).

- More effective use of least-cost-formulation programs can be made.
- Current consumer demands for reduced fat/salt meat products (i.e., cannot be achieved by a straight fat/salt reduction) can be addressed.

Overall, there is still a debate in the scientific community as to the correct definition of finely comminuted meat products. The two definitions are meat emulsion and meat batter. The controversy arises from the interpretation of the mechanism responsible for holding the fat within the product. Figure 9.7 shows a schematic microstructure of a finely comminuted product where the small fat globules are dispersed within an aqueous protein phase. Borchert et al. (1967) were among the first to show the presence of an interfacial protein film surrounding the fat globules, and they suggested that the film is responsible for stabilizing the fat. The myofibrillar proteins, which have hydrophilic and hydrophobic sites, can position themselves in such a way that they reduce surface tension and, hence, coalescence forces responsible for fat separation. Other researchers have suggested that the protein matrix is responsible for physically entrapping the fat globules in place (Lee, 1985). According to the physical entrapment theory, the viscous protein matrix restricts the fat globule's movement and, hence, coalescence. However, the whole issue of which mechanism is more important is not so simple, because numerous changes take place during the production of products such as bologna (Figure 9.8). During the initial stage of chopping, a flowable product with a paste-like texture is formed (i.e., the product can be moved around by a pump). Later

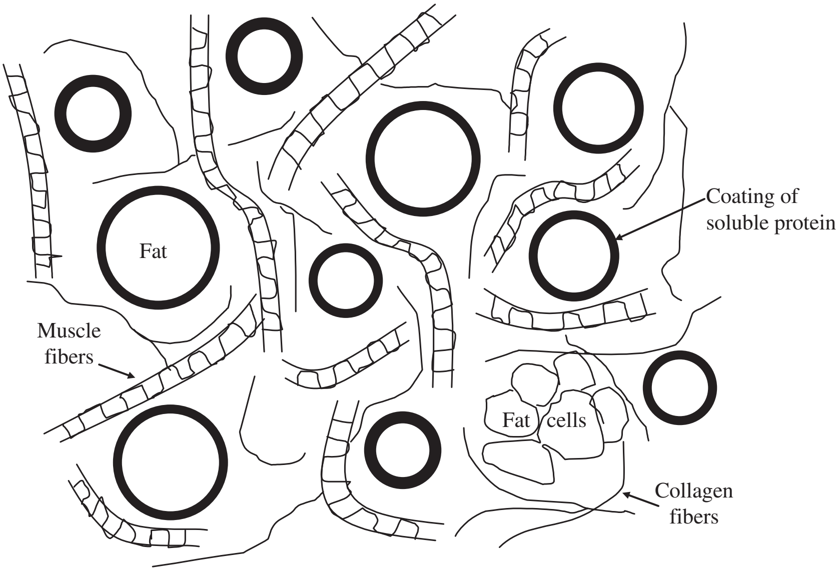


Figure 9.7. *A Schematic Structure of Finely Comminuted Meat Products.*

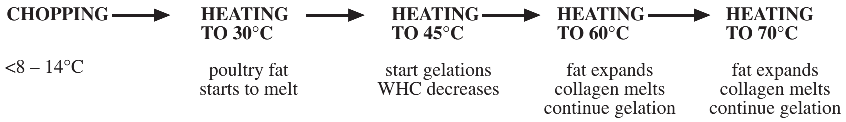

CHOPPING
HEATING TO 30°C
HEATING TO 45°C
HEATING TO 60°C
HEATING TO 70°C
<8 – 14°C
poultry fat starts to melt
start gelations WHC decreases
fat expands collagen melts continue gelation
fat expands collagen melts continue gelation

Figure 9.8. *Steps in Producing a Finely Comminuted Product.*

during the initial cooking process, the fat starts to melt and is present in a liquid form. Myofibrillar protein denaturation and gelation starts at a later point. At that point, the melted fat starts to expand, collagen starts to be transformed into gelatin (i.e., liquid form) and the salt-soluble proteins (mainly actin and myosin) form a gel. The texture of the product at the end of the cooking process (i.e., at 70–75°C) is semirigid and does not flow anymore, because the salt-soluble proteins have been denaturated. Figure 9.8 illustrates the complexity of the whole process. Overall, there is currently more support for the notion that fat stabilization is a combination of the ability of proteins to form an interfacial film and the formation of a gel matrix that physically restricts the movement of fat globules (Barbut, 1999).

Jones and Mandigo (1982) discussed the nature of the interfacial protein film in terms of its thickness, elasticity, the presence of a complete or partial coverage of the fat globules and weak spots along the film. They hypothesized that the formation of a relatively thin, flexible protein film around fat globules is desirable and emphasized the importance of pore formation as a “pressure release mechanism” during the cooking stage (i.e., when fat is expanding). By varying chopping procedures, they experimentally modified the thickness of the protein film. They observed that the formation of a relatively thin and flexible protein film provided the best stability, whereas a thick, inflexible film resulted in large ruptured holes during cooking. Figure 9.9 illustrates the microstructure of stable and unstable fat globules in two different poultry meat batters. The overall structure of a meat batter can also be seen in Figure 14.6, where a lower magnification was used. In the stable batter, fat globules are usually confined in a distinct globular structure. Increasing the salt from 1.5–2.0% is associated with higher protein extractability and, hence, a reduction in liquid and fat losses during cooking (Acton et al., 1983). The fact that liquid and fat losses from a meat batter occur together has been mentioned by Schmidt (1984), who observed that fat losses usually follow moisture losses. Schmidt postulated that the formation of channels through the meat batter is important to allow moisture and fat losses. Figure 9.9(a) illustrates a fat globule that has lost some if its fat during cooking. The insert shows a fat globule that has lost even more fat. Both photos demonstrate the existence of a protein envelope around the fat globule. When too much fat was exuded from the globule (insert), the protein envelope shrank, and indentations and small exudative holes could be seen on the surface. When salt was increased, little or no fat was lost, and round globules could be seen [Figure

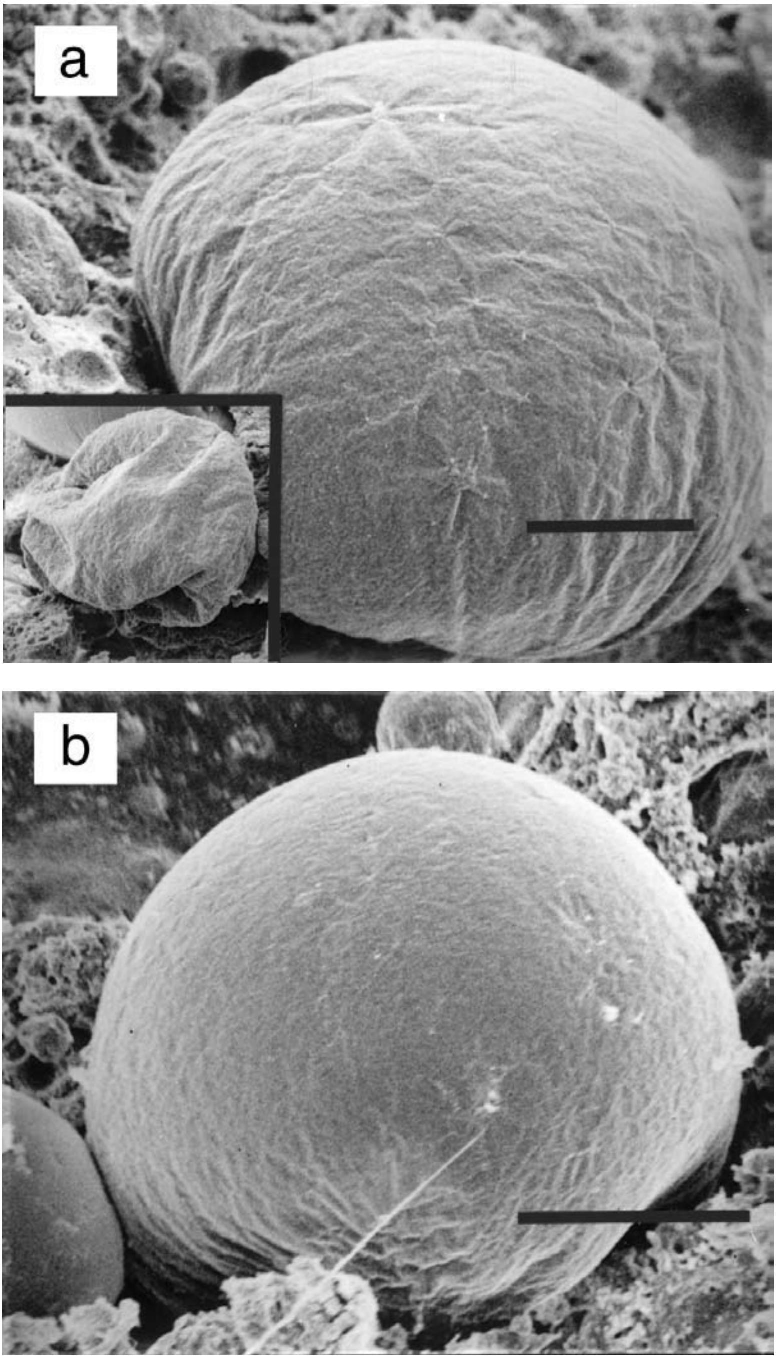


Figure 9.9. Scanning Electron Micrographs of Fat Globules in a Cooked, Low-Salt Poultry Meat Batter Formulated with 1.5% NaCl (a), and with a Medium Salt Level of 2.0% NaCl (b). Bars = 10 μm. From Barbut (1988). With Permission.

9.9(b)]. Whiting (1987) has also reported that 1.5% salt is a borderline salt level in frankfurters as determined by the amount of fat and water released during cooking. It should be mentioned that the amount of salt required to produce a stable batter also depends on the fat level, the amount of the proteins and their quality (Whiting, 1987).

Least Cost Formulation (LCF) Programs

Simple formulation of a meat product requires some basic calculations. However, in a modern processing plant that produces dozens of different products and relies on many raw materials at costs that fluctuates on a daily basis, the use of a computer program to optimize production can be very helpful. In the past, processors mainly used simple formulations with only a few raw materials because of the time involved in calculating complex formulations. In the late 1950s, linear programming for sausage manufacturing, as well as for other formulated foods and animal feed rations, began to be developed. The original term, least cost formulation, might have been a little misleading for people not familiar with the process (i.e., thinking that the goal is to formulate an inexpensive product). However, an examination of the procedure reveals that the program is designed to select the lowest cost meat ingredients after all the requirements (e.g., protein content, bind value, color, fat level) have been met. Pearson and Tauber (1984) indicated some of the main advantages of the program:

- It will give the most economical combination of ingredients for a given product within the limitations placed on each ingredient in the formula.
- It permits complicated calculations that would not otherwise be possible.
- It makes possible a savings in time alone over the more laborious traditional calculation (pencil or machine), which can be devoted to other production problems.
- It permits adjustment of formulas on the basis of analysis, using values obtained from pre-blending or other sources.
- It maximizes the use of available ingredients.
- It can help reduce inventory.
- It supplies accurate procurement information.
- It can be utilized for making management decisions on production, pricing and labor utilization policies.

However, it should be remembered that computer programming of least cost formulations requires even more basic information on ingredient composition as well as skilled personnel compared to traditional sausage formulation. Understanding of the scientific principles involved in emulsion stabilization and the functional properties of raw materials has become far more important as the number of raw materials has increased. As a result, more limitations/constraints have become necessary in order to maintain the quality of the finished product. Two important examples are the bind value and the emulsification capacity value that had to be established for different meats.

Saffle is generally credited with introducing the concept of meat "constants" in the early 1960s (La Budde and Lanier, 1994). The "constants" are based on the meat emulsion stability test (see Chapter 14) and were needed to develop sausage LCF programs. Overall, the linear programming requires numerical values to describe each meat's specific properties in order to come up with the best combination of raw material selection. An average processor might be dealing with 25–50 different meat cuts/trims on any given day. The program calculates the best combination of ingredients after satisfying requirements set by the operator. The requirements can include protein, fat and moisture content as well as color. A bind value is also required to obtain a certain texture of the product (Pearson and Tauber, 1984). It is important to note that when Saffle developed his constant emulsification value, at least one major North American company had already developed its own criteria for evaluating meats. Saffle's constant emulsification values are based on multiplying the percent of salt-soluble proteins in a certain cut of meat by the emulsifying capacity results. The bind value is still used today by several LCF programs. Estimates by one of the LCF program manufacturers suggest that about half of the medium- and large-sized meat companies in the United States are using the Saffle's values for LCF in one form or another. It should be mentioned that some of the large meat companies have developed their own proprietary criteria for rating meats, and they use these values in their in-house-developed LCF programs.

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CHAPTER 10

Battering and Breading

INTRODUCTION

THE consumption of battered and breaded poultry products, sold at retail and food service operations, has increased tremendously during the past three decades. In 1996, it was estimated that 1.2 billion pounds of food products were breaded in the United States (Figure 10.1), with poultry leading, followed by seafood and vegetables (e.g., onion rings). Breaded products represent a convenient food item that is tasty and can be prepared to fit most consumers' needs. One of the best success stories is the chicken nugget product that was introduced to the North American market by the fast-food chains in the 1970s. Originally, the product was made from a whole breast muscle strip that was battered and breaded and then fried. Today, chicken nuggets are made from whole muscle breast meat, ground breast meat, chunks of dark meat, ground dark meat with and without the inclusion of mechanically deboned meat and skin. The traditional oval shape of the nugget has also been modified in some markets (e.g., dinosaur-shaped nugget is a common shape used to attract young children). The breading and spices used also vary, depending on the market. A discussion concerning the different types of coating, breading and processing procedures used in the manufacturing of poultry products will be provided in this chapter.

Overall, battered and breaded products are coated products in which the meat protein component (e.g., whole muscle, ground meat) is the core, surrounded by a cereal base (e.g., wheat flour, cornstarch) coating as is shown in Figure 10.2. The coating operation can range from a very simple homestyle operation to very complex production lines requiring equipment worth millions of dollars. A simple, old homemade process, which seemed to originate in Europe, consists of dipping slices of chicken breast muscle in dry flour, followed by quickly dipping in an egg batter and then breading from both sides while pressing the crumbs into the meat. This is followed by frying in a pan filled with hot oil, and the final product was called "chicken schnitzel." The "schnitzel" is served right away and has a very attractive fried smell and a crispy texture. Commercial chicken nuggets go essentially through the same process; however, the processor of a

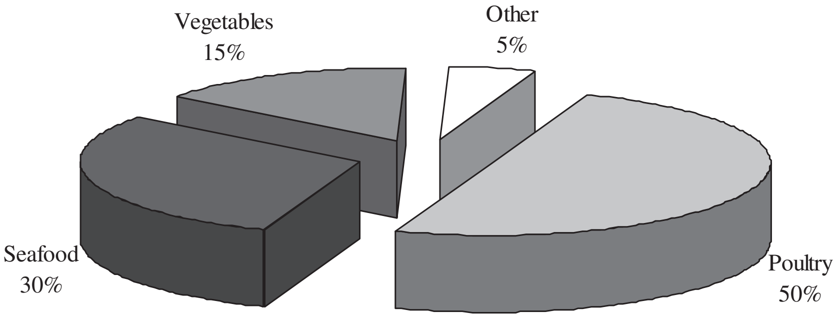

Figure 10.1. *Amount and Distribution of Breaded Products Produced in the United States in 1996. Adapted from Anonymous (1998).*

high-speed batter and breading line must pay much more attention to details, cost and potential problems. A commercial product has to be produced in an efficient way and be able to maintain full breading coverage despite various transfers between the different pieces of equipment and during freezing (most products are sold frozen). It should also withstand transportation stresses where vibration can break off poorly adhered coating. Other challenges include coating of an uneven product (e.g., chicken wings) in an automated process, etc.

The history of commercial breading lines in North America dates back to 1937 when a breading mix was applied to fish fillets in St. Louis, Missouri. The history of breading equipment followed this marketing development when Dr. S. Hart of Syracuse University, New York, designed the first successful machine. At the beginning, labor-intensive breading lines depended on numerous people battering and breading the product, by hand, where consistency and sanitation were serious problems. The equipment basically duplicated the hand operation, and for each coating step, a separate machine was developed (Suderman and Cunningham, 1983). Today, some of the modern automated lines can produce thousands of nuggets per hour (e.g., 6,000) without a human touching the product.

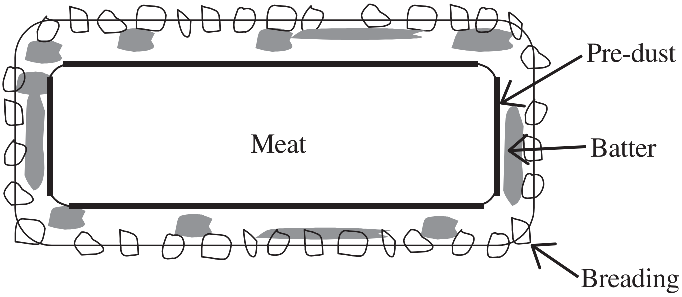

Figure 10.2. *A Cross Section of a Battered and Breaded Chicken Nugget.*

A schematic diagram of the different components used in a commercial operation is shown in Figure 10.3. The steps illustrated in the figure are the ones most commonly used; however, some can be left out (e.g., pre-dusting), while others can be repeated a few times, such as double or triple passing through the batter/breading operation to increase pickup deliver certain coating attributes. Frying is employed to achieve a full-fried product or is done for a very short time, called par-fry (e.g., 30 seconds at 190°C) to “cement” the breading to the surface and develop a nice brown color. In some cases, the product bypasses the fryer and is quickly frozen.

The battering and breading process is used to coat many different poultry products. Some examples include the following:

Bone-in product	Chicken wings
	Chicken drumsticks
	Chicken parts (eight cuts)
Deboned whole muscle	Chicken breast (skin on)
	Turkey breast fillet (skinless)
	Chicken Cordon-bleu
Ground meat	White meat nuggets
	Dark meat nuggets
	Chicken patties

During the process, dry and/or wet ingredients are applied to the moist surface of a regular or marinated (moisture-enhanced) meat. Proper adhesion represents a challenge to the processor depending on the roughness (skin on, skin off), temperature (partially frozen, thawed), amount of moisture on the surface (semi-dry or wet after forming), fat on the surface, etc. A general overview of chicken nugget production is shown in Table 10.1 (see also Figure 12.3 for the

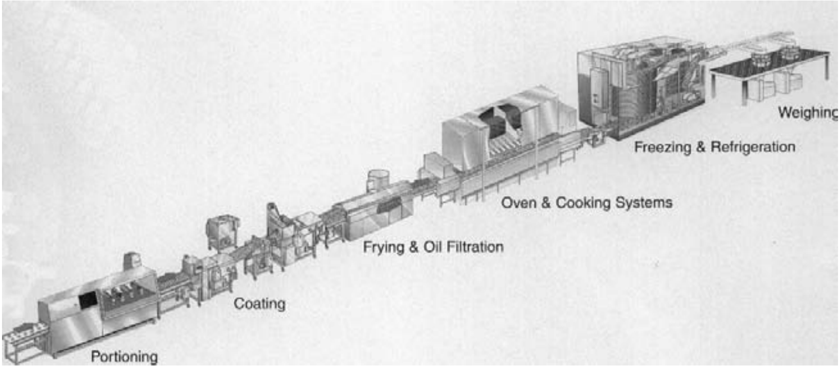

Figure 10.3. *A Schematic Overview of a Battering and Breading Process Typically Used for a Chicken Nugget Operation. Courtesy of Stein DSI, Sandusky, OH, U.S.A.*

Table 10.1. Flow Diagram for Chicken Nugget Production and Approximations for Pickup Values. Courtesy of Stein DSI, Sandusky, OH, U.S.A.

Step	Process
Form	21 g chicken nugget formed from white, dark or white plus dark meat.
Pre-dust	With flour to ≈6% pickup. Pre-dust equipment shown in Figure 10.4.
Batter	With overflow battering equipment (Figure 10.9) to ≈5% pickup. Batter's viscosity should be about 12 seconds in a Stein viscosity cup (Figure 10.7).
Bread	With free-flowing breading equipment (Figure 10.11) to ≈27% pickup (note, in the United States, usually up to 30% pickup because of labeling regulations; in places like Canada, it can be 40–50%).
Par-fry	At 190°C for 25 seconds using a continuous fryer (Figure 10.14). Expect about 100% yield coming out of the fryer.
Freeze	Mechanical freezing or cryogenic (see Chapter 7).

steps involved and HACCP implementation). The terms pickup and yield are commonly used in breading operations. Pickup, in the U.S. regulations, refers to the amount of coating material adhering to (or picked up by) the product and is based on the finished weight. For example, a chicken wing weighing 40 g battered and breaded to 50 g has a pickup of $(50 - 40)/50 \times 100 = 20\%$. In the United States, there is a restriction indicating that a product with $>30\%$ pickup must be labeled as a fritter. Therefore, a lot of products do not exceed 30% pickup prior to frying. It is important to note that different countries may have a different definition for pickup that is not necessarily based on the finished weight. Some use the initial ("green") meat weight as the basis for the calculation. Therefore, local regulations should always be checked. The term yield is commonly used (including in the United States) for cooking and is expressed as gain/loss of weight based on the initial substrate weight.

The battering and breading process, which may include all or some of the basic steps (pre- dusting, battering, breading and frying), will be discussed below.

PRE-DUSTING

As the name implies, pre-dusting is the process of coating the meat (or other products such as vegetables, cheeses) with a fine coating of flour, very fine bread crumbs or a combination of the two. The pre-dust is commonly used as the first layer prior to the application of the batter and breading; however, it is not used in all products, and the decision to apply pre-dusting depends on factors such as the wetness of the surface, extracted proteins on the surface (i.e., achieved by tumbling/massaging the meat), availability of equipment, etc. The pre-dust adheres to the surface by absorbing free water at the surface and is later used to form an intermediate layer between the product and subsequent batter. It is important to remember that the surface of the product must be preconditioned prior to the pre-dust application. A frozen surface or ice crystals at the surface will interfere with the binding of the fine flour particles. Therefore, attention should be given to the product temperature and amount of free water on the surface. Enhancing pre-dust adhesion can be achieved by adding non-meat proteins such as soy, egg albumen and whey to the pre-dust mix or by utilizing the meat proteins after tumbling with salt and extracting the myosin and actin.

It is important that the pre-dust material has good flow characteristics to minimize clump formation. Flour, which is most commonly used for this application, usually does not flow very well by itself and, therefore, various flowing agents are added. Clumping is not only a problem with equipment operation (e.g., jamming), but also with obtaining uniform products (e.g., an unusually thick pre-dust layer can result in dry areas that will not absorb the next batter layer and leave bare spots). In order to minimize thick pre-dust problems, a blower and/or agitating belt is usually installed at the exit from the pre-dusting unit. An example of a flatbed pre-duster is shown in Figure 10.4. The pre-dust is applied from the top and bottom while the product is moving on a mesh-type conveyor belt. The product is usually transferred from

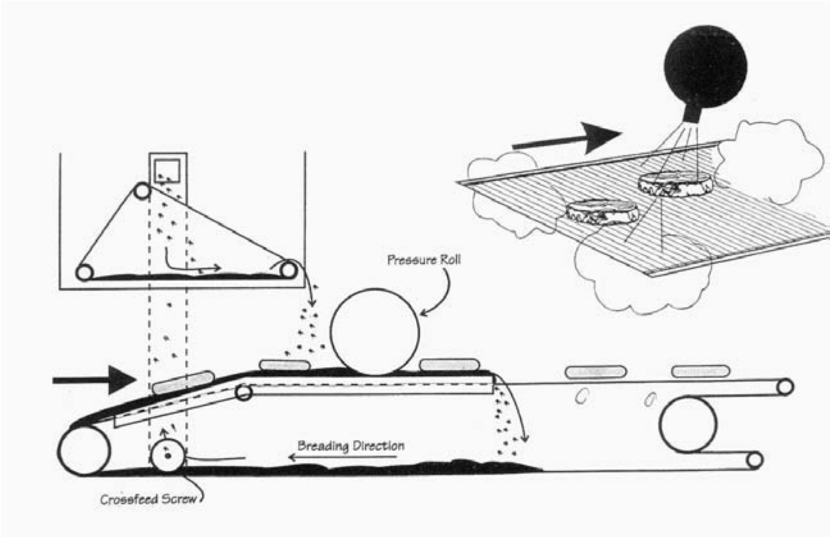

Figure 10.4. *Pre-Dust Application Using a Flatbed with an "Air Knife" Blowing Mechanism. Courtesy of Stein DSI, Sandusky, OH, U.S.A.*

another belt and initially falls onto a pre-dust layer that should be evenly distributed. Free-falling pre-dust material is applied from the top, and then the product is passed under pressure rollers that ensure close contact between the pre-dust and the substrate. The substrate is transferred to another perforated belt where air blowers (also known as "air knives") are used to blow off the excess amount of pre-dust (Figure 10.4). Other methods of removing the excess amount of pre-dust include a vibrating conveyor belt, which basically shakes off the excess amount, or a flip mechanism, whereby the product falls onto a lower belt and the excess pre-dust is knocked off. The flatbed application is ideal for uniform meat products (e.g., preformed chicken nuggets) that have an even surface and geometry. However, flatbed is not satisfactory for products such as bone-in chicken wings, drumsticks or thighs. For such applications, a drum applicator is commonly used (Figure 10.5), where the product falls onto a bed of dry pre-dust material. The drum, which works like a cement mixer, is positioned on an angle and rotates at a relatively low speed (rolling and falling). The product, which starts at the top, is slowly moved forward while submerged in the pre-dust material. The dwell time can be adjusted to achieve the desired amount of pickup prior to discharging the product. Also, in this case, removing the excess amount of pre-dust is important and can be done by an air blower, vibrating conveyor belt or a flip mechanism.

A third type of pre-duster, the flip coater (Figure 10.6), is also useful in coating irregular-shaped products. In this case, flipping onto a second belt covered with additional pre-dust material assists in achieving uniform coating.

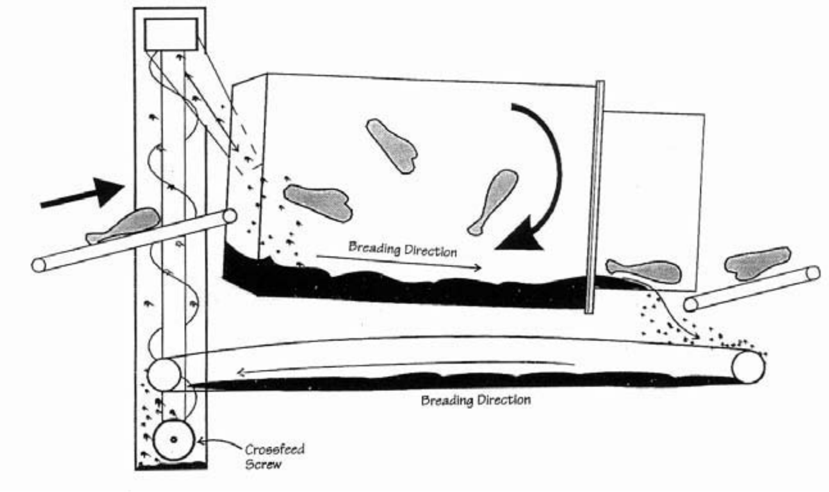

Figure 10.5. *Pre-Dust Application Using a Drum. Courtesy of Stein DSI, Sandusky, OH, U.S.A.*

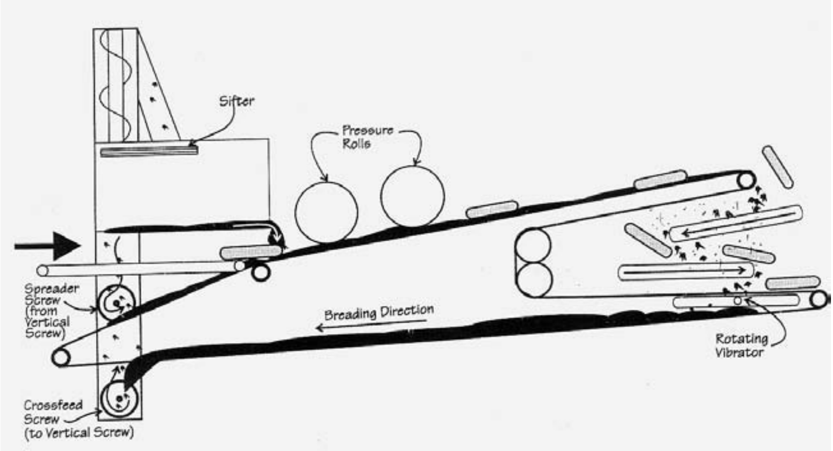
Sifter
Pressure Rolls
Spreader Screw (from Vertical Screw)
Breading Direction
Rotating Vibrator
Crossfeed Screw (to Vertical Screw)

Figure 10.6. *Pre-Dust Application Using a Flip Mechanism. Courtesy of Stein DSI, Sandusky, OH, U.S.A.*

The pre-dust material is often used to carry seasonings and spices. This is advantageous because flavor components are fairly volatile. Embedding them under the batter and breading layers can assist in "protecting" them and reducing the amount needed as compared to seasoning the outer layer.

BATTERING

Batters are a suspension of dry ingredients used to coat the product. Batters can be divided into three main categories:

- adhesion batters that are designed to adhere to the meat product
- cohesion batters that are designed to form a shell around the product
- tempura batters that are usually not breaded later on and are used to create a puffed layer around the product

With all three batters, it is important that a certain degree of binding or "glueing" be achieved between the outer layer and the product. The rate of surface drying (rate at which the batter, or later the breading, can absorb moisture) is another crucial factor in maintaining an adequate batter layer. This is especially important with automated equipment where the product continuously moves on wire-type conveyor belts.

Most batter and breading mixes are purchased by the poultry industry from ingredient companies specializing in baked goods. The main ingredients found in a batter usually include wheat flour, corn flour, proteins, gums and leavening agents. Not all of these ingredients have to be present in a single batter, and different ingredients can be selected to achieve certain functional properties (e.g., binding of breading, crispy outer layer). Overall, the two most commonly used ingredients are wheat flour and cornstarch. The major components used in batters are discussed below.

Wheat flour is obtained by finely grinding the wheat's endosperm. It contains carbohydrates and proteins. The carbohydrate component, mainly consisting of starch, is useful in providing good adhesion to the product. Modified starch can be used to further enhance adhesion. Starch also contributes to the texture of the fried product and the drying time of the freshly applied batter. The starch molecules, which are made up of linear glucose polymers with some branching, absorb water during batter preparation and later some oil during the frying phase. The latter is used to develop a crispy texture during frying. In some batter applications, the ratio of highly branched starch (amylopectin) polymers and linear (amylose) polymers has a profound effect on the starch functionality. The ratio is quite variable and ranges from 99% amylopectin in waxy rice and waxy corn to 75% amylose in high-amylose corn.

Proteins are used for their adhesion and texture-binding development properties. Wheat proteins (mainly gluten), egg proteins, dairy proteins and soy proteins can be used. Initial binding is achieved during the battering phase and is greatly enhanced during the cooking operation, when the proteins denaturate and form a rubbery matrix. As a texture-building ingredient, proteins firm up during the heating process and form a gel structure. A common example is the transformation of liquid egg proteins to an elastic structure during the preparation of a scrambled egg mix. Emulsification can also be achieved by employing proteins that are capable of forming an intermediate layer between fat and moisture. Some proteins have better emulsification characteristics (e.g., caseinates) than others and should be used when the need arises for creating/maintaining a water and fat mixture.

Gums are used to assist suspending different solid ingredients by controlling viscosity and water holding. Hydrocolloids such as xanthan, guar and modified cellulose gums are helpful in increasing the viscosity of products such as sauces and gravies. In battering applications, they are used to increase viscosity and reduce run-off problems during the process (i.e., controlling the amount of batter staying on the product). Certain gums, such as methyl cellulose, are used because they can increase the viscosity and form a gel during heating. The latter can help in reducing fat absorption during the frying operation by creating a "protective" film around the product.

Leavening agents are used to produce air spaces within the coating layer. This, subsequently, provides a unique textural characteristic (e.g., crispiness) to the fried product. The most common agent used is sodium bicarbonate, which is added with one or more acids to help release the gas. When hydrated, CO_2 is released, and most is expected to be entrapped within the batter, assisting in increasing the volume of the final product and making the outer layer less dense. In addition, the air spaces can contribute to the way light is reflected from the surface (i.e., color of the product). The rate of CO_2 release depends on factors such as the type of acid, the bicarbonate granulation, temperature and time.

Flavoring (spices, salt and sugar) can be used to flavor the product. Black and/or white pepper usually represents the major component of the spices used, together with smaller quantities of dried thyme, celery, marjoram, rosemary oleoresin, etc. The amount of seasoning can vary considerably among products, but on average, they account for 3–5% of the dry batter, with salt representing 10–15% of the mix of flavorings. When sweet flavor notes are desired, various sweeteners are used.

Coloring ingredients (spices such as paprika) can be used to enhance the red color of the outside layer (artificial food colorings are usually not permitted in all countries). In addition, caramel ingredients or ingredients that will enhance the Maillard browning reaction (i.e., between reducing sugars and amino acids) can be used to enhance the golden color development on the final product.

It is important that the batter material has good flow characteristics and forms a homogenous mixture that will not separate into its components shortly after mixing the dry ingredients with water. If separation is a problem (e.g., high cornstarch batters where the cornstarch tends to settle down), a gentle mixing is required prior to use. The most common way of controlling the batter's flow characteristics is by checking its viscosity. This is very important in controlling the amount of batter remaining on the product and in achieving a consistent amount of pickup. A viscosity cup such as the one shown in Figure 10.7, is commonly used on the processing line to measure batter viscosity. Batter viscosity is expressed as the time it takes to drain the cup from a predetermined volume. Commercial-type viscosity cups, such as Zahn and Stein, are sold by laboratory supply distributors and often are supplied with the battering equipment. The cup's volume, the size of the orphus and the batter's temperature are the extrinsic factors controlling the time measured. The ratio of dry ingredients to water and the type of dry ingredients are the intrinsic factors determining the flow time. It should also be noted that overworked batters can result in lower viscosity values (or time to drain the cup).

Some typical time values for a Stein cup are as follows:

- adhesion batter, which mainly contains starch: 9 to 12 seconds
- cohesion batter, which mainly contains flour: 28 to 30 seconds
- tempura batter, which contains a mixture of starch/flour: 45 seconds

As can be seen, an adhesion batter is considered to be thinner than both cohesion and tempura batters. The viscosity also translates to the amount of pickup that is rated as low, moderate and high for adhesion, cohesion and tempura batters, respectively. Because the drying rate is also affected by the

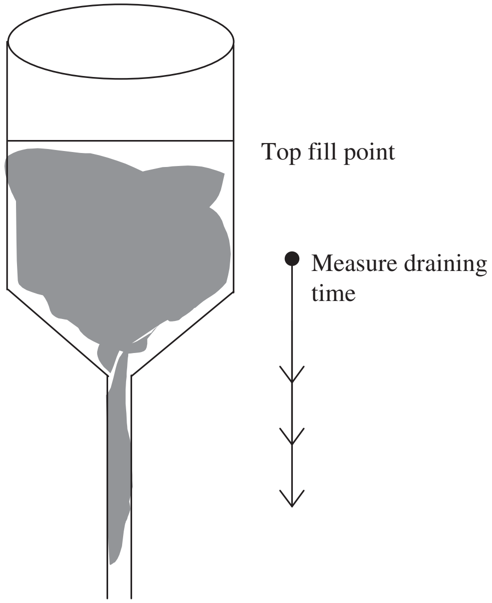

Figure 10.7. *A Typical Viscosity Cup Used to Adjust Batters' Viscosity. Time Measured to Empty the Cup at a Given Temperature Is Measured with a Stopwatch.*

thickness of the batter, it is usually rated as fast, moderately slow and slow, respectively.

The characteristics of the three types of batters are discussed below.

Adhesion batters are usually starch based with a high solid content and low viscosity. The main ingredient is cornstarch or modified cornstarch. Such a batter is usually applied as a relatively thin coat that can adhere nicely to the surface of the meat. A layer of salt-soluble proteins extracted from the meat (e.g., by tumbling) can be helpful in enhancing the adhesion characteristics. The batter is used as a "glue" for the next coating system (breading). It is important that such a batter dries fairly quickly (e.g., by combining with the predust layer), so that a significant amount stays on the product and provides a good base for the breading. This is especially important in such a low viscosity batter in which the next layer of bread crumbs should not absorb an excessive amount of moisture from the batter. The type of starch can be matched to the line speed so as to control the drying period.

The common dilution of dry ingredients (solids):water is 1:1.4 to 1:1.9.

Cohesion batters are used to form an envelope around the meat product and as a base for "cementing" the next coating layer. These batters are thicker than adhesion batters and are usually flour based. They contain a medium amount of solids and are used to provide texture to this layer. The drying time is longer than for adhesion batters, but because they are more viscous (28–30 seconds, as measured by the Stein cup; Figure 10.7), they will not run off as quickly.

The common dilution of dry ingredients (solids):moisture is 1:1.5 to 1:2.

Tempura batters are cohesion batters that include a significant amount of leavening agents. These batters are used as an outer coating that is not usually supplemented with breading. The final meat product, after deep-fat frying, has a puffed coating layer that is crispy with a lot of air spaces. Tempura batters are usually made from a mixture of flour and starch and have a high solids content. This results in high viscosity of the batters (around 45 seconds in the Stein cup at a temperature of 5–10°C). The batter is designed to have good cohesive characteristics and, as a result of the leavening ingredients, will form a layer rich in air pockets. The inclusion of leavening agents makes the batter much more sensitive to overmixing and pumping. Extra care should be given to the amount of agitation because a high degree of mixing will result in a fast release of the gases (e.g., CO_2) that are supposed to be released during the frying operation. Overall, it is recommended that the product be fried very soon after applying the batter.

The common dilution of dry ingredients (solids):water is 1:1 to 1:1.3. This results in a high pickup of the batter and a slow drying rate. The batter is applied by dipping and not by overflow as is the case with the other two batters (see later discussion). The time between coating and frying should be carefully controlled. These batters contain cornstarch which contributes to disruption of the structure (or a tenderizing effect) when the wheat flour hardens during the frying operation. Different tempura batters are available to the poultry industry and can be designed to address various products' needs. A typical home recipe for a tempura batter has basically the same ingredients and usually calls for flour (1 cup), cornstarch (1 tablespoon), salt (1 teaspoon) and an ingredient to produce gas bubbles such as club soda (1.5 cups). Some of the more sophisticated recipes call for beer as the source of gas. Eggs are also included in some recipes.

Batter Preparation/Mixing

Dry, pre-mixed batters are commonly used by the poultry industry. The ingredients arrive at the plant in sacks or drums and should be kept in a dry area to minimize potential moisture absorption. When needed, the dry ingredients are mixed with water at a predetermined rate. Figure 10.8 shows a typical mixer used for preparing the batter, where cold water (5–10°C) is recommended for use. Some mixers have a built-in viscometer with an outside readout panel that can be used for quality control purposes. In other cases, a manual viscosity measurement, such as with a Zhan or Stein cup, is used. Attention

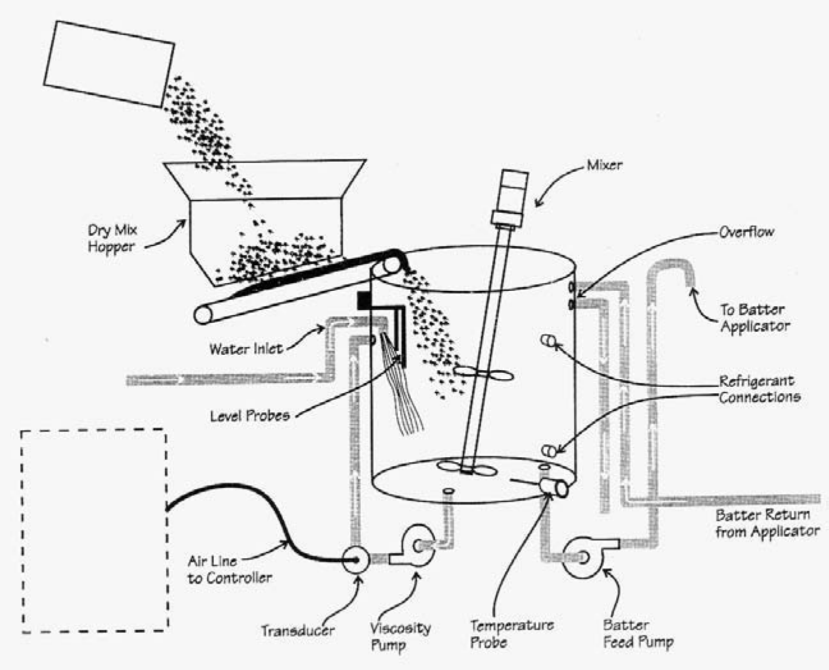

Figure 10.8. *A Mixer for Batter Preparation. Courtesy of Stein DSI, Sandusky, OH, U.S.A.*

should be given to creating a homogenous mixture and preventing clump formation. When ingredient settling is a problem, such as with cornstarch batters, constant mixing should be applied.

Applications

Achieving an even coating of the batter is extremely important. It is usually easier to achieve this with uniform, flat products as compared to products with uneven surfaces (e.g., chicken drumsticks, wings). The most common batter application is the curtain application, also known as an overflow application (Figure 10.9). In this case, the batter is pumped from a reservoir or the mixer into a trough that overflows and cascades to coat the product from the top. Later, the product is dipped in a well-like cavity and coated underneath. This can be used for an unleavened application where mixing and pumping do not adversely affect batter quality.

For leavened batters, a submerging application is used. This is also called top-submerging, where the product moves into a pool of batter and is coated from all sides (Figure 10.9). It is important to remember that the conveyor

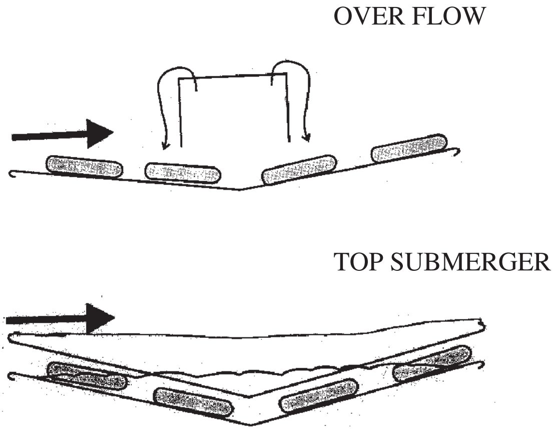

Figure 10.9. Batter Application Using a Curtain-Overflow and Top-Submerging. Courtesy of Stein DSI, Sandusky, OH, U.S.A.

belt is a mesh-type belt (e.g., wide patch, ⅜ inch) that also allows the batter to be covered from the bottom. Top-submerging application is designed to minimize pumping, because too much agitation and pumping can result in a fast release of the gases from the leavening agent.

BREADING

Breading is usually applied on top of the batter and is used to enhance appearance and texture as well as increase the volume and weight of the product. The type of breading can range from simple, unbaked flour to very structured baked crumbs. Usually, the breading is a cereal-based product that has been baked and ground into fine, medium or large crumbs. The dry breading material adheres to the product via the "sticky" batter. Therefore, it is important to match the batter with the right breading. Today, most breadings are manufactured on continuous baking lines employed by large baked goods companies. Such lines consist of a large mixer for combining the flour, water, salt, sugar, etc. The mixer forms the dough that is extruded and rolled to form loaves or continuous sheets of dough. They can be baked fairly quickly (when chemical leavening agents are used) or go through a resting period prior to baking (when yeast is used). The loaves or continuous sheets of dough are baked and then allowed to cool and dry to a certain degree. This is followed by crumbling through a granulation mill or a slow-speed grinder. The crumbs can be allowed to dry further to a desired moisture content, because it is easier to dry smaller particles with a large surface area. Later, the crumbs are usually sifted and blended as needed for a certain application.

The most common types of breading are shown in Figure 10.10 and include the following:

(*1*) Flour provides for an economical way to coat a product and often is used for full-fry products. The resulting fried coating provides relatively low browning of the surface and a very dense coating matrix. Special equipment should be used for this very fine and dusty material as to prevent it from blowing all over the plant. The expected pickup is fairly low, meaning that increases in the product's weight are not high.

(*2*) Traditional/cracker-type crumbs are usually white or colored bread crumbs with minimal or no crust on the surface. This is an inexpensive type of crumb and is considered by some to be a commodity item. The breading has a flat-like flake structure that is easy to use on a high-speed processing line. It is usually made to have a fine granulation that

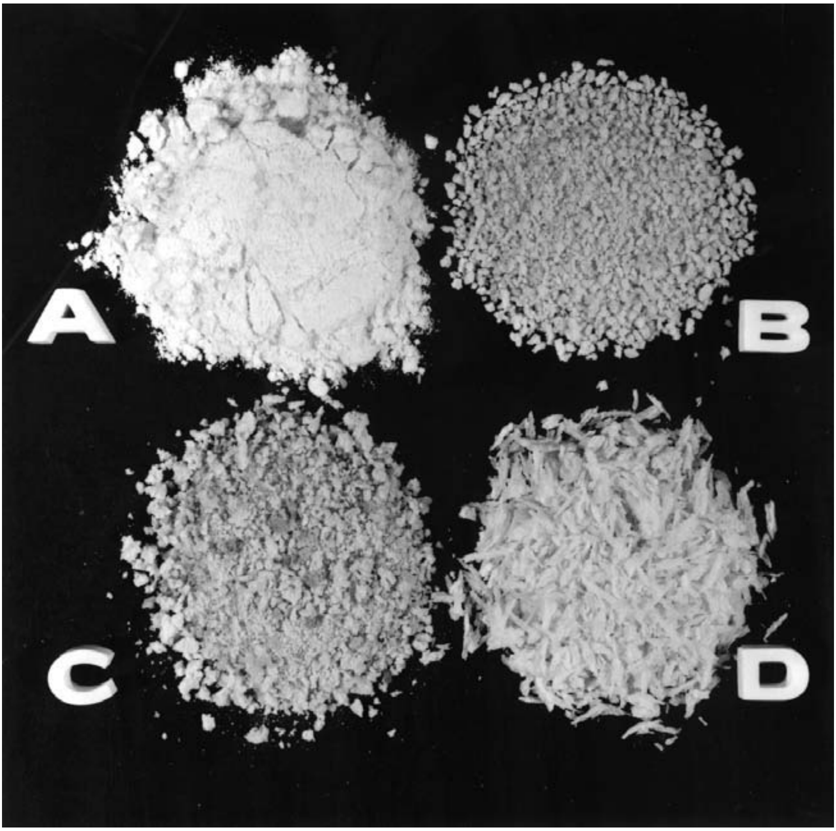

Figure 10.10. *The Four Major Types of Breading. Flour (A), Cracker crumbs (B), Home Style (C), and Japanese Style (D). Samples Courtesy of Griffith Inc., Scarborough, ON, Canada.*

results in an even surface on the coated product. The browning, achieved during the frying operation, is considered low (also depends on the addition of a browning agent, such as dextrose) and the crumb can be used for full-fry or oven-heated-type products. The cracker-type crumb can be used in a pre-dust or a conventional application. The flakes are fairly dense and, hence, the final product will have a crunchy texture.

(*3*) Home-style or American bread crumbs resemble the type of crumb consumers can prepare at home. The crumb has a distinct crust that provides a nice highlighting during the frying operation—a medium to high browning can be achieved. It has a more open structure compared to flour or the cracker-type crumb which results in a more crispy texture of the fried product. In terms of pickup, medium to large quantities can be used to coat the product. The cost of this crumb is higher than flour and cracker-type crumbs, but not as expensive as the Japanese crumb.

(*4*) Japanese-style crumbs have a defined shape that resembles an elongated spindle (i.e., like shredded cheese). Because the delicate, three-dimensional structure can be easily broken, special equipment should be used for its application. The texture of the crumb is fairly open/porous and is produced as white or colored. The crumbs are commonly produced by an electrical induction heating process, rather than conventional baking. This allows the production of a very light density crumb without the formation of the crust seen in home-style crumbs. Because of its light structure, it is possible to produce a large-sized crumb without the sensation of a hard particle, which is prevalent in other crumbs. The product can be used for full-fat fried or oven-heated products. It is usually the most expensive crumb of the four and is used in special applications where the substrate can justify the cost. The amount of pickup can be controlled from medium to high. In addition, the degree of browning during the frying operation can be controlled to be medium light to dark.

Breading Application

Automated equipment used for breading application is shown in Figure 10.11. The meat product coming from the battering operation is transferred, via a wire mesh conveyor belt, to the breading applicator, where it falls on a layer of dry breading while more breading is sprinkled on the product from the top. The amount of breading is designed to be much larger than the amount the product can pick up. After coating, the product usually goes under a gentle pressure roller that physically helps to embed the breading onto the batter layer. The pressure from the rollers should be adjusted to control the amount of pickup. Some rollers are filled with air, and the air pressure is used to adjust the force applied. After the rollers, air blowers and/or vibrating belts are used to remove the excess breading, so an even coat is formed. Not

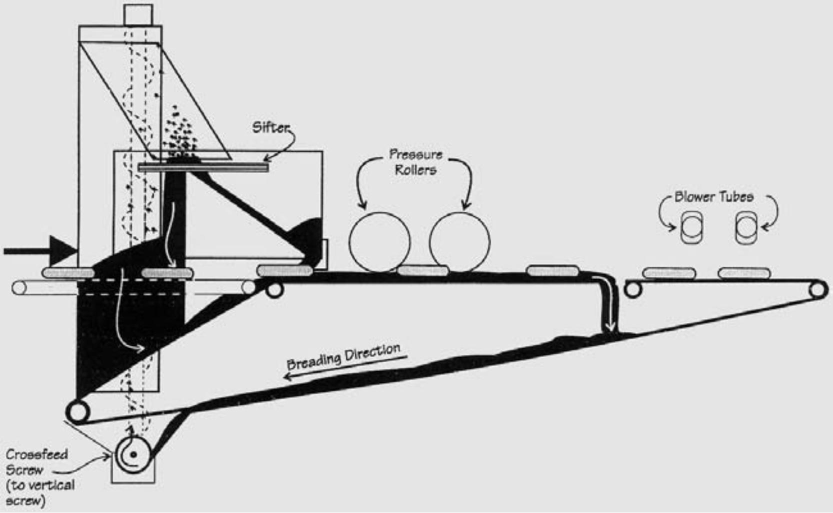

Figure 10.11. *Breading Application—Free-Fall Crumbs. Note: for Japanese Crumbs, Special Equipment with Very Gentle Handling Is Required. Courtesy of Stein DSI, Sandusky, OH, U.S.A.*

removing the excess breading could result in losses on the conveyor belt, but more troubling is the discharge of loose breading and flour particles in the fryer. This can cause cleaning problems that would require additional filtering of the oil because excessive burning of the fallout breading particles is damaging to the oil quality and, subsequently, the meat products. Fallout crumbs that stay in the fryer for an extended period of time will turn to charcoal that can be deposited on the product. For the Japanese-type crumbs, the same basic equipment (Figure 10.11) is used; however, moving and transferring the crumbs is done in a much gentler way, which is necessary to prevent damage to the crumb structure. It should be remembered that the crumbs are "recycled," meaning that the crumbs that are not picked up during the first application are sent back for another application. This movement and transfer can be damaging to the crumb structure if special care is not provided.

For flour application, the same idea of dropping the product onto a belt covered with flour and later sprinkling sifted flour from the top is employed. However, the equipment should be able to handle more dusty components and provide a nice even coating of the product (Figure 10.12). At the end of the operation, air blowers/air knives are used to remove the excess amount of flour.

Breading granulation is divided into three categories. The size is used to achieve different functional attributes:

- Fine refers to flour application, but can also be used to describe other types of small-particle (greater than 60 mesh) breading. Sometimes, a free-flow agent is used in a flour-type application to reduce stickiness

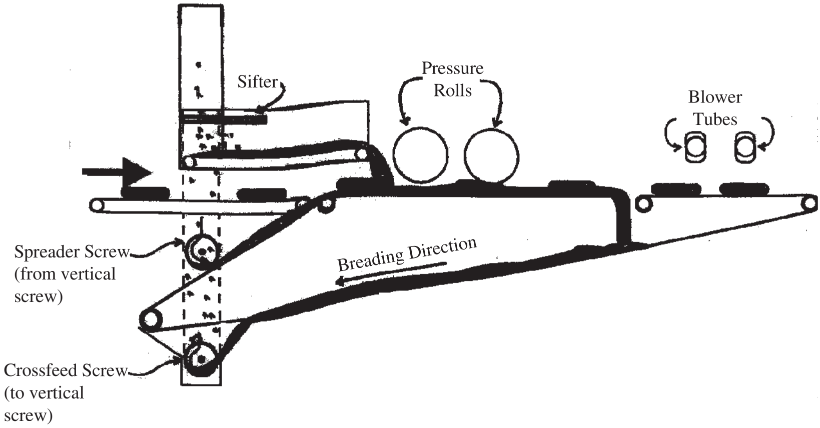
Sifter
Pressure Rolls
Blower Tubes
Spreader Screw (from vertical screw)
Breading Direction
Crossfeed Screw (to vertical screw)

Figure 10.12. *Breading Application for Flour. Courtesy of Stein DSI, Sandusky, OH, U.S.A.*

and clumping problems. The amount of pickup is considered low compared to the medium- and coarse-sized breading. For a straight flour application, special equipment that includes sifters for breaking down the "recycled" clumped material should be used.

- Medium refers to particles with size distribution of 20–50 mesh. These crumbs can have a higher pickup volume and, therefore, can increase the weight of the product more significantly than the fine crumbs. The medium crumbs can provide uniform coverage. The amount of pickup can be controlled to address market preference and cost (i.e., depending on the meat vs. the breading value). It is interesting to note that in some extreme cases, the coated product is less expensive than the breading (e.g., onion in onion rings), whereas in others, the product is much more expensive (e.g., chicken breast fillets).
- Coarse refers to fractions up to 5–20 mesh size. These crumbs can provide the highest amount of pickup but will sometimes result in poor coverage compared to the fine or medium crumbs. The coarse breading provides a crispier texture because of its larger particle size. Overall, as breading size increases, perceived crispiness will increase. In addition, the appearance of coarse crumbs is very distinct on the surface of the product and provides what is known in the industry as "highlighting," which is partially affected by more browning on the high points of the coarse breading particles.

Color and Browning

Breading can be white, have a brownish crust or be colored with spices such as paprika (orange/red color). In addition, caramel ingredients can be used to obtain a distinct dark color, depending on consumer preference for a certain breaded product. Overall, color and appearance are very important because most buying decisions concerning packaged foods are based on these two factors (see also Chapter 13 for discussion on color). The meat inside the breaded product is obviously invisible to the consumer, therefore, the outside appearance, including "highlighting" and browning, is of utmost importance.

Battered and breaded products destined for home use are usually par-fried prior to shipment. This means that the product is fried for a very short period of time (less than 1 minute) to "solidify" and cook the outside layer so it will adhere to the surface of the product during the freezing operation, and later during transportation to the store (i.e., withstand moving and shaking). Par-frying also requires fast browning so the product develops a nice golden appearance. Only a small amount of additional color is expected to develop in the oven at home. The degree of browning during the par-fry operation can be enhanced by adding proteins and reducing carbohydrates, such as dextrose, to enhance the Maillard browning reaction (see also Chapter 13, compounds contributing to the Maillard reaction). For products designed for the food service industry, slow-browning crumbs are commonly used, and most of the browning is achieved during the second heating operation (i.e., prior to consumption).

The amount of oil absorbed by the crumbs during par-frying depends on factors such as the quantity, size and porosity of the crumbs. Dense structures will absorb less fat than very porous structures. The size of the crumb also affects absorption, where fine crumbs with a large surface area usually absorb more fat than coarse crumbs. As mentioned earlier, certain gums can be used to reduce the amount of fat absorbed during the frying operation.

Some of the main ingredients used in breading production are similar to the ones used for battering (e.g., flour), the other special ones are described below.

Leavening agents are used for gas production during the baking operation and add porosity to the breading. They may consist of live yeast cells or chemicals such as baking powder. By incorporating gas into the structure, the volume is increased, and a crunchy texture is obtained.

Flavors, such as different spices or spice extracts, can be added to the breading to provide unique flavor notes. As mentioned earlier, spices added to the outer layer are not as protected during the frying operation as spices used in the pre-dust layer.

Coloring and browning agents can be added to enhance the appearance of the product. Because most consumers expect a brown/golden color on breaded products, the fast development of such color is important to the manufacturer. As indicated before, a significant number of retail products are deep-fat fried for a short period of time prior to freezing and shipping, and therefore, fast color development is important. Spice extracts such as paprika can be used to provide a red color that later provides the breading with a more intense color.

The addition of reducing sugars and proteins provide substrates and enhance the Maillard reaction, which will contribute to a darker appearance of the product.

Modifying agents, ingredients such as fat conditioners and emulsifiers, may be added to modify the textural characteristics of the breading. Such ingredients can also affect the increase in volume of the breading during the par-fry operation and modify the bite characteristics of the crumbs.

DEVELOPING A BATTER AND BREADING SYSTEM

Meat

The different coating components of the system (pre-dust, batter and breading) should be developed to match the meat product's characteristics. The surface of the raw meat can vary from an exposed cut breast muscle to a skin-covered drumstick. These two surfaces have very different physical properties and require different approaches. Furthermore, a lean muscle surface can be pre-marinated to induce a more moist and sticky surface covered with extracted meat proteins. Good adhesion of the batter and breading to the meat surface is of great importance. Suderman and Cunningham (1980) studied batter adhesion to chicken skin using scanning electron microscopy and developed a model for describing adhesion to broiler skin with cuticle [Figure 10.13(I)] and without cuticle [Figure 10.13(II)]. The latter applies to broilers

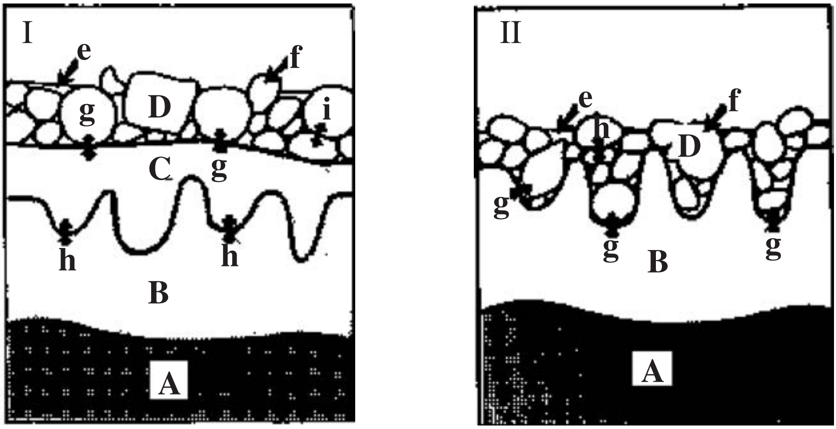

Figure 10.13. *Theoretical Model of Physical Adhesion of Breading to (I) Poultry Skin with Cuticle and (II) without Cuticle. The Model Features Are (A) Dermis, (B) Stratum Germinativum, (C) Stratum Corneum (Cuticle), (D) Coating Matrix, (e) Coating Ground Substance, (f) Coating Particles, (g) Primary Binding Forces and (h) and (i) Secondary Binding Forces. From Suderman and Cunningham (1980). With Permission.*

exposed to a high scalding temperature (≥60°C), which results in removing the outer cuticle layer, as was described in Chapter 4. According to the model (Figure 10.13), removing the cuticle improves the batter's adhesion to poultry skin because particles can lodge between protrusions extending from the stratum germinativum. Overall, it is important to note that poultry can be processed in different ways (e.g., high/low scalding temperature) that affect the skin surface.

Meat temperature can significantly affect the adherence of the coating material. A frozen or partially frozen product surface can create problems with the pre-dust or batter during the coating operation. Ice crystals on the surface can result in an uneven distribution of the dry ingredients. If the product is too warm, problems such as "marriages" and tails can occur (see Troubleshooting section below).

The amount of "free" moisture on the surface is critical to the proper adherence of the pre-dust and batter. In some cases, pre-formed nuggets have an excess amount of water on the surface that results from spray nozzles being used in the forming machine. This can potentially result in an uneven deposition of the dry ingredients and later show as "bald" spots on the finished product and poor adhesion of the coating material.

When developing a battering and breading system, a clear idea of the desired final product is helpful. Accordingly, different ingredients can be selected, and the amount of pickup predetermined. It is vital to recognize consumers' expectations in terms of appearance, price and textural characteristics, which determine the type of batter and breading materials to be used.

Coating Materials and Procedure

The coating line can include different station arrangements (Figure 10.3). The most simple arrangement consists of pre-dusting and a single battering and breading operation. Such a system, consisting of flour coating or only batter and fine breading, will result in a pickup of $<30\%$. A multiple (e.g., double, triple) battering and breading operation can be designed to obtain $>30\%$ pickup. A tempura battering line, which commonly includes a pre-dusting operation followed by a thick batter application, usually results in 30–55% pickup. The use of a fryer in a tempura operation is a must, unlike in a conventional battering and breading operation where immediate frying is optional (i.e., the product can be immediately frozen). It should be noted that, in most conventional breading operations, the product is par-fried to enhance batter adherence and color development.

Overall, the texture of the coating material can be designed to be tender or hard, porous/airy or very dense and compact. The level of crunchiness and crispiness can be modified. Appearance can be determined by the size of the crumbs and can vary from an even surface to a highly detailed surface when small or coarse crumbs are used, respectively. Additional ingredients, such as sesame seeds or dried parsley, can be added to achieve a more distinct differentiation on the surface. The intensity of the brown/golden color can be controlled by adding spices such as paprika, food coloring and the incorporation of ingredients contributing to browning via the Maillard reaction. The equipment available in the plant also determines the type of application possible. As mentioned earlier, Japanese-type crumbs are very delicate and require special equipment to maintain a certain throughput when the machine is running (i.e., to minimize recirculation) and stop during breaks. Overall, if special equipment is not available, Japanese crumbs should not be used.

FRYING

The frying operation is used for two main purposes. The first is to develop a brown/gold color on the surface. The second is to "solidify" the coating system so it will better adhere to the product during the later distribution phase (e.g., vibration during transportation). Frying, at the processing plant, can be done for a short period of time (par-fry; less than 1 minute) or for a long period of time which results in a fully cooked product. The decision depends on market requirements. A schematic diagram of a fryer is shown in Figure 10.14.

Different oils can be used and are usually divided into vegetable (e.g., soybean, canola) and animal (e.g., tallow) fats. Using one oil vs. another depends on factors such as cost, consumer demands (e.g., less saturated fat, health concerns), allergy concerns (e.g., peanuts), stability and flavor.

Oil quality should be monitored on a continuous basis. Filtering and partial oil replacement are also used to maintain oil quality. The high temperature employed during the frying operation (180–200°C) can induce fast chemical changes in the oil and affect its quality. As time progresses, oil hydrolysis (release of free fatty acids) and oxidation take place. In addition, polymerization causes further deterioration of the oil's quality in terms of flavor, color

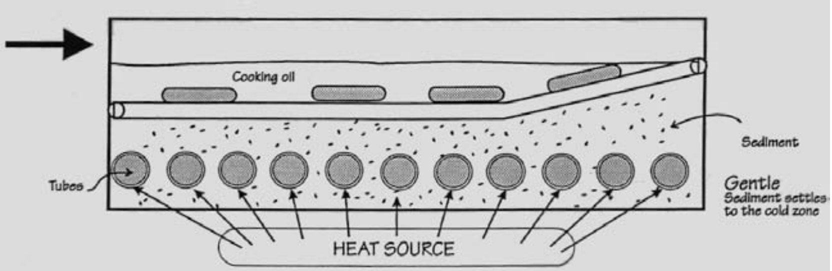

Figure 10.14. *A Schematic Diagram of a Continuous Fryer. Courtesy of Stein DSI, Sandusky, OH, U.S.A.*

and nutritional value. Deterioration of the oil in terms of darkening is the most visible because it results in darker products coming out of the fryer. The breaking down of fatty acids and foaming of the oil can result in bubbling and splashing and, thus, cause safety problems around the operation.

The increase in oil viscosity over time can cause a problem with increased oil pickup by the breading and also insufficient heat transfer. In a conventional operation, the oil is usually filtered on a continuous basis to remove charcoal particles (fall-off bread crumbs, etc.), and fresh oil is added on a continuous basis to replace oil absorbed by the products. Usually, about 10% of the oil is absorbed and must be replaced. This oil turnover, coupled with constant filtering, usually allows for an adequate continuous frying operation. It should be noted that the oil absorbed by the product is mostly replacing water lost during the frying operation.

For the par-fry operation, a dwell time of 20–30 seconds is usually used at an oil temperature of 195–200°C (Table 10.1). There is a trade-off between oil temperature and product quality. At a lower temperature, more oil will be absorbed by the product, whereas at a higher temperature, the oil will deteriorate faster.

Final Heating

If the product is only par-fried at the processing plant, it must be fully cooked by the consumer/food service operator. Fully cooked products (at the plant) are usually reheated/warmed by the consumer prior to consumption. The way the product is going to be prepared/heated by the consumer dictates the type of breading ingredients used by the processor. Battered and breaded products requiring full cooking can be prepared in an oven, deep-fat fryer or microwave. Each of these unique cooking methods requires a different combination of ingredients. Whereas microwave heating is employed for a relatively short period of time, oven cooking usually requires a longer period (≥30 minutes) of time because heat is transferred from the outside to the inside of the product. During microwave heating, problems such as sogginess can develop (still a challenge to the food industry). Therefore, it is recommended that the breading supplier be involved in the design of the coating system.

FREEZING

After frying, the product is usually frozen in order to preserve its freshness, crispiness and appearance. The frozen product is less prone to oxidation and to peeling of the coating material. It should be mentioned that slow freezing tends to result in moisture migration into the coating layer and loss of crispiness. The typical freezing methods include the following:

- Mechanical freezing, where a blast freezer, at different belt configurations (e.g., linear, spiral) can be used (see Chapter 7).
- Cryogenic freezing is popular for small poultry products, where CO_2 or liquid nitrogen is used to dip or spray the product and freeze it very quickly.

The fast cryogenic freezing operation (e.g., $-79°C$ for CO_2) is more expensive than mechanical freezing, but results in very small ice crystal formation and less damage to the product (see Chapter 7). Individual quick freezing (IQF) is used for small products such as nuggets.

The freezing operation should be monitored and controlled to prevent problems such as cracking the coating, which can result from very rapid freezing of the outside surface. In some cases, the initial freezing is done in a freezing tunnel, and the rest is achieved in the warehouse where the product is commonly stored at $\leq -20°C$.

As a summary of the development of a coating operation, an overview of the production of bone-in chicken products (e.g., drumsticks, nine-piece cut) is shown in Table 10.2, and a high added value chicken cordon bleu product is shown in Table 10.3.

Table 10.2. Flow Diagram for Breaded Chicken Parts and Approximate Pickup Values. Courtesy of Stein DSI, Sandusky, OH, U.S.A.

Step	Process
Marinate	Inject and tumble bone in chicken parts (average size: 28 g) with 12% marinate. Keep temperature at 4–6˚C.
Pre-dust	With flour to ≈6% pickup. Using drum-type pre-dust equipment (Figure 10.5).
Batter	With top-submerge equipment (Figure 10.9) to ≈5% pickup. Batter's viscosity should be about 12 seconds as measured with a Stein viscosity cup (Figure 10.7).
Bread	With free-flowing breading equipment (Figure 10.11) to ≈25% pickup.
Par-fry	At 190˚C for 60 seconds using a continuous fryer (Figure 10.14).
Cook	In a continuous oven at 205˚C for ≈13 minutes until an internal temperature of 80˚C is achieved. Use steam injection and leave fan on at 100% speed for hot air circulation. Expect 120% yield from raw meat (≈89% from oven).
Freeze	Mechanical freezing (see Chapter 7).

Table 10.3. Flow Diagram for the Production of Chicken Cordon Bleu. Courtesy of Stein DSI, Sandusky, OH, U.S.A.

Step	Process
Prepare	Stuff boneless, skinless chicken breast pieces (≈225 g each) with ham and Swiss cheese slices. Overall dimensions of the product 15 × 7 × 5 cm. Maintain a temperature of 0°C.
Pre-dust	With a flour coating (Figure 10.4).
Batter	With top-submerge equipment (Figure 10.9). Using batter viscosity of ≈15 seconds as measured with a Stein viscosity cup (Figure 10.7).
Bread	With free-flowing breading equipment (Figure 10.11) to ≈25% pickup.
Par-fry	At 190°C for 30 seconds (Figure 10.14).
Cook	In a continuous oven at 196°C for ≈10 minutes until an internal temperature of 80°C is reached. Use steam injection and leave fan on at 100% speed to obtain good hot air circulation. Expect ≈90% yield from raw product.
Freeze	Mechanical freezing (see Chapter 7).

TROUBLESHOOTING

Various problems can occur during battering and breading operations. The problems are usually visible in the finished product but may be detected and corrected during the process itself (i.e., prior to frying, when it is not too late to correct the problem). Usually the operator(s) will adjust/correct the process over time to eliminate minor imperfections. For major problems the line will have to be stopped. A description of some of the common problems and potential cures are provided below.

Excess/insufficient pickup—seen as thick or thin coating layer—can result from mismanaged batter where the viscosity is too high or too low, respectively. Therefore, the batter's viscosity should be monitored on a continuous basis, as should the batter's temperature. The belt speed used within the breading machine should be adjusted to obtain an appropriate dwell time. Adjusting the amount of pressure applied by the rollers and the airflow of the "air knives" used to strip excess amounts of batter and breading should be controlled.

Uneven coating is an obvious defect to the consumer and should be avoided as much as possible. A low-viscosity batter can result in an uneven batter deposition and later no or insufficient breading sticking to this area. Partially frozen or icy surfaces can result in insufficient pre-dust and/or batter adherence. An oily surface or greasy patches on a meat cut will result in the same problem. Fast-moving conveyor belts and overloading can also cause the problem. Overall, enough time and spacing among products should be allowed for each operation (i.e., timing is very important when products are transferred from one belt to the next). Inadequate transfer from one belt to another can also result in excessive shaking and damage the integrity of the previous coat deposited on the product.

"Marriages," also called "doubles," result in fried products sticking to each other. Inadequate line speed during transfer from a fast-moving belt to a slow-moving belt can result in products falling on top of each other and sticking together. In addition, product floating in the batter equipment can attach to each other. Adequate spacing, adjustments of line speed and the depth of the batter's well are required to address the problem. Sticky batters can also result in "glueing" two adjacent products.

Belt Marks appear as elongated lines on the product (also causing uneven surfaces) caused by too much pressure applied by the rollers in the breading operation (see Figure 10.4) and inappropriate absorption of breading to the surface. This usually requires adjusting the breading formulation. High viscosity of the batter can also result in visible belt marks.

Flares and Tails result from an excess amount of batter staying attached to the fried product. High batter viscosity can result in tails remaining on the product. The excess batter can be removed by increasing the air pressure used for the blowers and, where required, adjusting the batter's viscosity. Large amounts of breading attached to the product can also result in flares and tails. This might require changing the type of breading used or adjusting the pressure applied by the rollers at the exit from the breading machine.

Dark color is seen as dark fried products coming out of the fryer. A high temperature in the fryer can result in fast deterioration and darkening of the oil, which will then be transferred onto the product. (Note: flour will deteriorate oil faster than crumbs.) An excessive frying period will result in burning of the surface. This requires adjusting the belt speed and reduce exposure time to the oil. The components added to the breading can also be adjusted to control the browning rate (see previous section).

Ballooning is seen after the frying operation as a separation of the coating from the product that can later cause cracking and cause the breading material to fall off. Ballooning can result from fast hardening of the outside coating system during the par-fry operation, while not allowing water vapor to easily escape from the product. If the batter is too cohesive, the problem can be magnified. Therefore, the viscosity should be adjusted as well as the thickness of the batter deposited on the product. The latter can be controlled by the air blower at the end of the battering operation. Changing the pre-dust from fine to medium particles (or medium to coarse) can create a more porous layer that makes it easier for water vapor to quickly escape from the product during the frying operation and minimize coating separation. Increasing the breading size can help by creating a more porous surface. And, adjusting the batter's ingredients, such as by adding fat or gums, can also modify the porosity of the coating system and allow moisture to easily come out during frying. In some cases, another approach is to focus on ingredients that better bind the moisture in the product.

Shelling is usually seen in tempura-type batters where a hard shell is formed prior to allowing the hot water vapor to escape from the product. A thick batter deposited on the product can form a hard shell around the product during the frying operation. Therefore, viscosity should be checked and adjusted as needed. In addition, the air blower should be adjusted to control the thickness of the material deposited. If the temperature is too high prior to the frying operation, an excessive amount of gas can be released. (Note: tempura batters are formulated to include a high level of leavening agents.) This will result in an insufficient amount of gas being released during the frying operation and reduced porosity of the batter. The hard coating can trap the hot air and water vapor inside the product, and eventually, a shelling problem will occur. A high amount of pre-dust deposited on the product and/or too much water on the substrate can also cause this problem. This might require a change in the type of pre-dust material used.

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CHAPTER 11

Microbiology and Sanitation

INTRODUCTION

FOOD safety is one of the most important issues in marketing any kind of food, and poultry meat is no exception. If consumers perceive that a product is unsafe, all other positive selling points (e.g., taste, price, nutritional value) become irrelevant. Overall, consumers have a healthy image of poultry products, even though there is some concern regarding raw poultry meat as a potential vehicle for certain foodborne diseases such as *Salmonella* and *Campylobacter*. As seen in Figure 11.1, the number of outbreaks of foodborne diseases in the United States associated with poultry is not proportionally higher than with other foods. In poultry, the two most common bacteria associated with foodborne diseases, *Salmonella* and *Campylobacter,* can result from cross contamination of raw and cooked products (e.g., using the same cutting board/knife to cut raw meat and cooked products) and undercooking of the meat. Both microorganisms can be present in the gut content or skin of healthy birds and might be carried onto the meat. Fortunately, both are heat sensitive (will be rapidly inactivated at about 65–70°C) and should not be transferred to humans if the meat is adequately handled. However, illnesses from each of these bacteria have an estimated annual incidence in the United States of up to 4 million cases (Bryan and Doyle, 1995). It is hard to obtain a precise estimate on the number of cases because most are mild and not reported. The annual rate (per 100,000 people) of four significant foodborne pathogens in the United States is shown in Figure 11.2. Still, this emphasizes the point that care should be taken in reducing potential contamination by all stakeholders. The industry is currently adopting a farm-to-fork philosophy where it is recognized that minimizing contamination requires all parties to participate. The process actually starts with the breeding stocks and continues through hatcheries, feed mills, farms, transportation trucks, processing plants, distribution channels and the consumer's own kitchen. In some countries, such as Sweden, a massive *Salmonella* eradication program has been going on for a few decades, resulting in the virtual elimination of *Salmonella* in poultry meat. The program involves strict government controls and voluntary

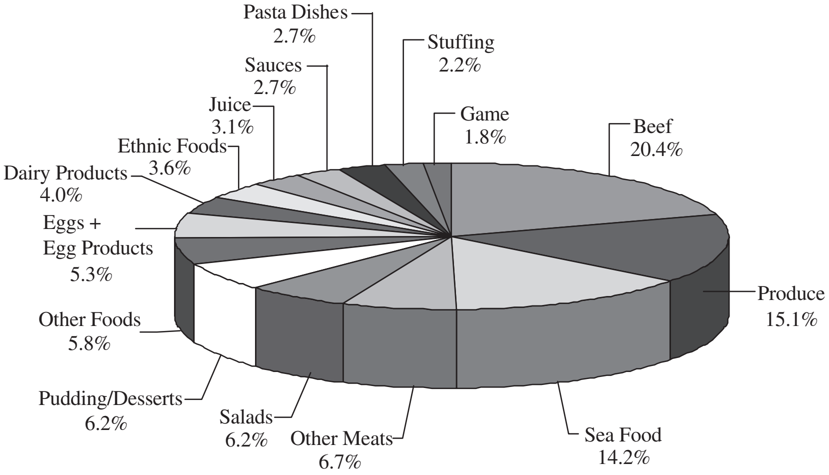


Figure 11.1. *Foods Associated with Foodborne Outbreaks (United States, 1990–1998). Adapted from CSPI (1999).*

measures by producers (e.g., elimination of *Salmonella*-positive flocks) but is very expensive to run (Persson and Jendteg, 1992). A few other countries (e.g., the Netherlands, Finland) are currently involved in extensive programs to reduce *Salmonella;* however, such programs are fairly expensive, and most countries have chosen to introduce some measures, but not all.

The following chapter is designed to provide the reader with a basic understanding of food microbiology, including the intrinsic and extrinsic factors affecting microorganism growth (e.g., storage temperature, pH, water activity) and common methods used to enumerate microorganisms. Later, a discussion

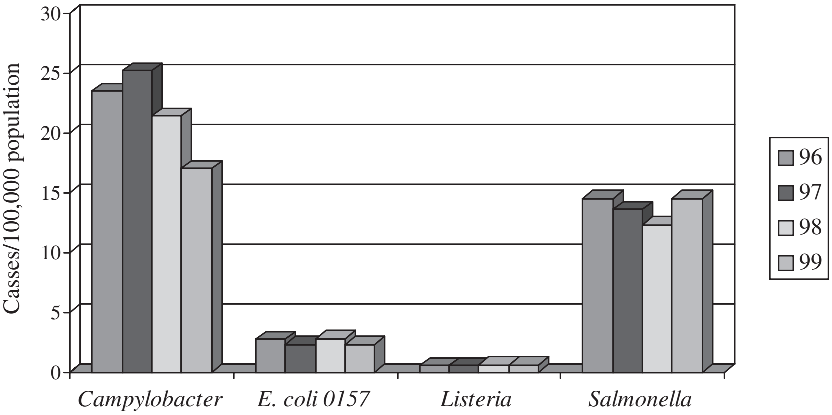


Figure 11.2. *Annual Rate of Common Foodborne Pathogens in the United States (1996–1999). From CDC (1999).*

on potential contamination sources (e.g., breeding stocks, transportation, further processing equipment) is provided, as well as a description of the most significant microorganisms associated with poultry meat, and an overview of poultry meat plant sanitation. Other chapters that are closely related are Chapter 7 on preservation methods and Chapter 12 on HACCP models.

TYPES OF MICROORGANISMS AND GROWTH

Microorganisms of concern can be divided into four major groups that include bacteria, yeast, mold and viruses. This section is intended to present basic microbiological principles that will assist the reader in understanding the following discussions in the chapter. It should be noted that the information in this section is not intended to cover all aspects of food microbiology. If the need arises, a comprehensive microbiology textbook should be consulted (see Reference section).

Bacteria are unicellular microorganisms ranging in size from 0.1–10 µm. They can be divided and sorted based on various criteria such as morphology, Gram reaction, colony shape and color, etc. One of the basic criteria is based on the shape (morphology) of the bacteria:

- Cocci are round microorganisms as shown in Figure 11.3. When they are found in chains, they are called *Streptococci*.
- Rods are rectangular in shape (Figure 11.3). They can be found as single rods or rods attached in an elongated chain.

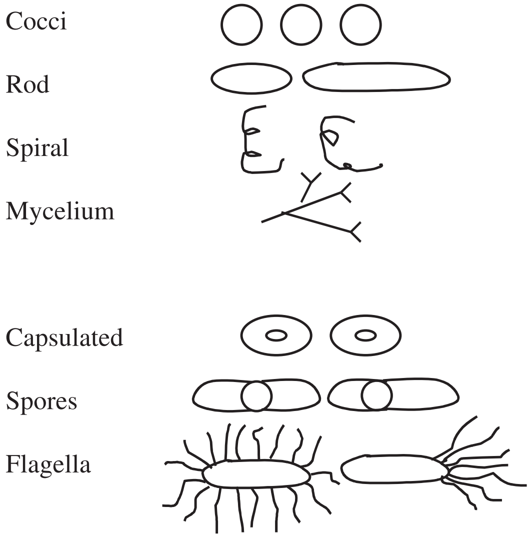


Figure 11.3. *Shapes and Structures of Various Bacteria. Average Size is 0.5–2 (Micron); Large Bacteria are 2–10 µm.*

- Spirals are narrow and elongated in shape and look like a small spiral (Figure 11.3).
- Mycelia have a branch-like appearance (Figure 11.3).

Bacteria can also be classified based on the specific structure(s) they possess:

- Capsulated structure, a coating secreted to resist adverse conditions (e.g., heat, chemicals), is mainly composed of polysaccharides (Figure 11.3). An example is *Pseudomonas,* where its structure accounts for sliminess appearing on the product when high numbers of this common poultry meat spoilage bacteria are present.
- Spores or very resistant "casings" can be formed by certain bacteria when exposed to adverse conditions (Figure 11.3). Its function is to resist heat, ultraviolet (UV) radiation and dryness and can allow the bacteria to be dormant and survive harsh conditions for years. Germination can be triggered by a heat shock, glucose or certain ions such as magnesium (Mg^{++}). An example is *Clostridium botulinum*. The spore-forming bacteria represent a challenge to the food industry because they survive boiling, where most other bacteria are destroyed. All canning operations are designed to treat food at elevated temperatures (e.g., 121°C) specifically designed to inactivate *C. botulinum* spores.
- Flagella are used as "paddles" to help the bacteria move (Figure 11.3). They can appear as a single flagellum or double or multi-flagella and are typical to certain species.

Another common way used to classify bacteria is according to their Gram stain reaction. This classification is based on differences in cell wall structure (Figure 11.4) while utilizing differential stains. The typical staining procedure consists of four steps.

(*1*) Flood the heat-fixed smear with crystal violet for 1 minute, all cells turn purple
(*2*) Add iodine solution for 3 minutes, all cells remain purple
(*3*) Decolorize with alcohol (20 seconds), Gram-positive are purple and Gram-negative are colorless
(*4*) Counterstain with safranin for 1 to 2 minutes, Gram-positive are purple and Gram-negative are red

Mold

Mold can appear unicellular or multicellular (Figure 11.5). When grown on food, it usually has a fuzzy or "cottony" appearance and may include a pigment (black, green or white) that will give it a distinct color. The fuzzy appearance is the result of the intertwined filaments (hyphae) and the whole mass called mycelium (Figure 11.5). They can reproduce sexually or asexu-

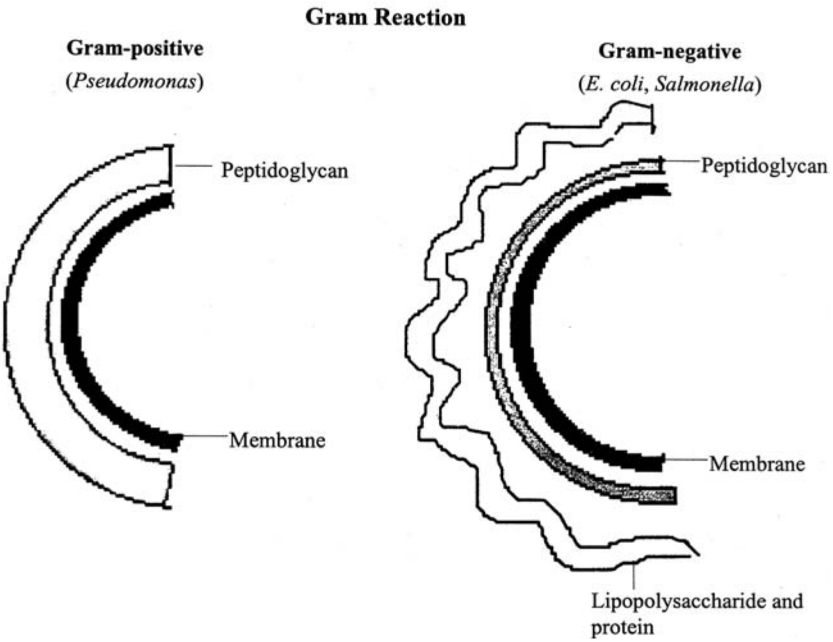


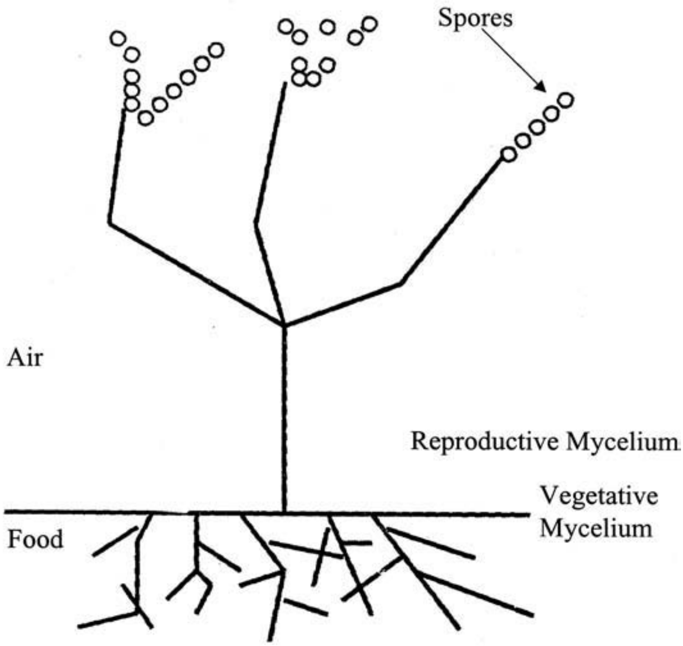
Figure 11.4. *Cell Membrane Components Affecting the Gram Stain Reaction.*

ally, and growth is possible at low water activity (as low as 0.65) and a wide pH range. If appearing on conventional poultry meat products, the food is considered unfit for consumption. However, it should be remembered that there are "good" molds that are used in the production of different cheeses (e.g., Roquefort, Camembert) and also on the surface of some dry fermented sausages (e.g., summer sausage). The latter is usually a white mold that gives the product a distinct appearance. Other examples include *Penicillium* that is used in human medicine as an antibiotic (i.e., a compound secreted by the mold that is used in nature to kill/suppress the growth of other microorganisms) and *Aspergillus*.

Yeast

Yeast are usually unicellular microorganisms, though sometimes they produce mycelium by fusion. Yeast cells can reproduce sexually or asexually by budding, as shown in Figure 11.5. They can grow at relative low water activity (a_w 0.87–0.94), pH values as low as 4–4.5 and at high salt concentrations (osmophillic 0.60–0.70 M) making them a potential problem in dry fermented products. A high yeast count in fresh poultry meat (can be introduced from water, the environment) results in off-odors, flavors and, in most cases, indicates that the meat is spoiled. Again, not all yeasts are "bad"; an example of

Mold



Yeast

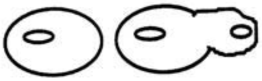


Figure 11.5. *Shape and Structure of Mold (Average Cell Size 10–40 µm, Structure a Few mm), and Yeast Cells (Average Size 5–10 µm) Showing Budding.*

a yeast commonly used by the food industry is *Saccharomyces,* also called "sugar yeast," used to ferment sugar into CO_2 and other by-products.

Viruses

Viruses are very small bacterial or fungal parasites. Their size is much smaller (0.01–0.2 micron) than bacteria or fungi cells, because they carry only genetic material (Figure 11.6) required for their multiplication inside the host cell. The genetic material can be in the form of DNA or RNA, which is injected into the host cell after the virus has attached itself to a specific cell membrane. Viruses are very specific to a certain host and to a particular type

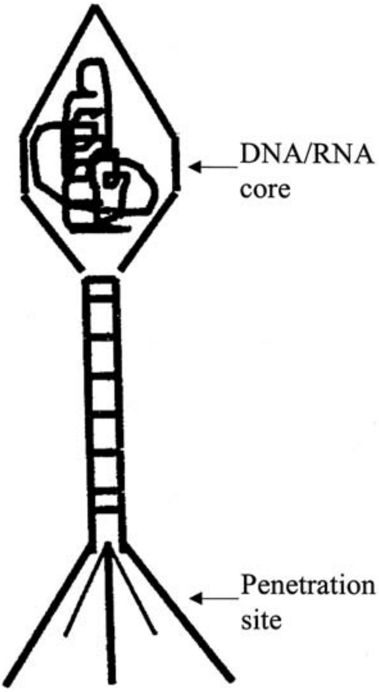


Figure 11.6. *Schematic Structure of a Typical Virus Particle. Average Size is 0.01–0.2 Micron.*

of cell within the host. Once genetic material is introduced into the host cell, it attaches itself to the host's DNA/RNA and instructs it to produce the viral clones. Thousands of clones can be produced within the host cell until it dies, and the new viruses infect other cells. Because viruses infect the host cells, it is hard if not impossible to destroy them without harming the host. Therefore, some mild virus infections (e.g., the common cold) are not even treated by doctors. The suggested "treatment" usually includes drinking plenty of fluids and waiting for the infection to go away. This is in contrast to bacterial infections that are treated by antibiotics that preferentially target the invading bacteria cells present outside the host cells. An example of a virus that can be passed from person to person by meat is the hepatitis A virus, which can be transmitted by an infected person or a carrier (i.e., a person carrying the virus but not showing any symptoms) to a heathy person. Cases of such occurrences by a sick family member, a restaurant employee, etc., are not uncommon. Therefore, care should be taken when a plant employee is known to have contracted the virus (see discussion later in the chapter), especially since, after recovery, the person may continue to be a carrier and shed the virus.

FACTORS AFFECTING MICROBIAL GROWTH

Different factors affect the proliferation of microorganisms in any given environment. The present discussion will focus on food, but the general principles can be applied to other situations.

Microbial growth curve: the development of a population, microorganism in this case, can be described as a mathematical model (Figure 11.7), where one microorganism divides into two, two into four, four into eight, and so on. The curve is composed of four phases:

(*1*) Lag phase—represents the adaptation time required by a newly introduced microorganism to adjust to the new environment. It is characterized by no or very slow growth rate. As will be discussed below, this is the state where we want to keep bacteria during storage of fresh and cooked meat (see also Chapter 7).

(*2*) Logarithmic growth phase—starts after the microorganisms have adjusted to the new environment and experience favorable growth conditions (e.g., temperature, nutrients). During this phase, the growth rate increases and then stabilizes. Because the growth is so fast, it is called logarithmic or exponential growth that describes the 2^2, 2^3, 2^4, etc., multiplication.

(*3*) Stationary phase—in which the growth rate starts to decline and then remains constant at a point where the number of new cells and dying cells are equal.

(*4*) Death/decline phase—takes place as the number of dying cells outnumbers new cells formed. This is usually seen when a limiting factor is approached (i.e., nutrient, accumulation of waste products) or when

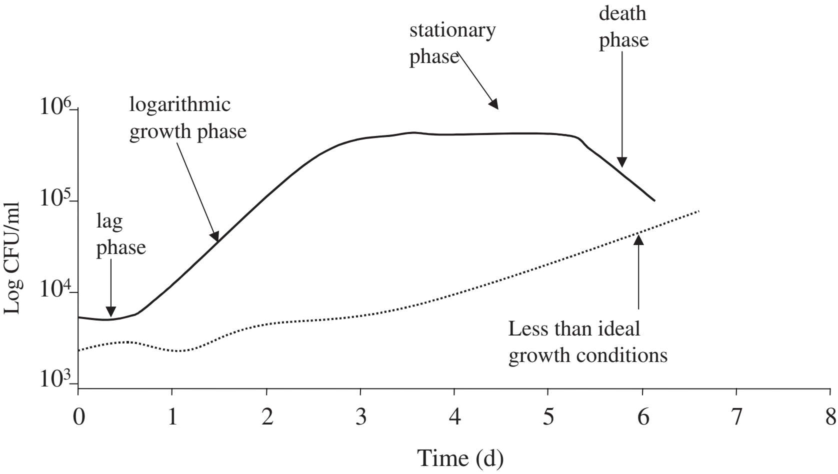


Figure 11.7. *A Typical Growth Curve for a Bacteria Culture.*

an outside factor such as heat or a sanitizing chemical is introduced. With many microorganisms, the numbers do not decline at a constant rate to zero but taper off gradually as low numbers are approached.

Microbial Inactivation

Various processes employed by the food industry are designed to inactivate/destroy microorganisms present in food. They include treatments such as low-temperature pasteurization, high-temperature sterilization and irradiation. In order to understand thermal destruction of microorganisms, it is important to become familiar with certain basic concepts. The first is thermal death time (TDT), which is an expression used to describe the time required to destroy/kill a given number of microorganisms at a specific temperature. According to this procedure, a known number of cells or spores is exposed to a constant temperature (i.e., microorganisms are kept in a sealed tube, can, flask or a capillary tube), and the time necessary to kill a certain number of cells is determined. Usually, this is done by placing a number of tubes/cans in an oil bath and removing them at the end of the heating period. The microorganisms are then placed on a growth media that is incubated at a suitable temperature. Death is defined as the inability of the microorganisms to form a visible colony.

The second term is *D*-value, which is defined as the time required to destroy 90% of the microorganisms at a certain temperature. Numerically, the value equals the number of minutes required for the survivor curve to traverse one log cycle. Mathematically, it is equal to the reciprocal of the slope of the survivor curve and is a measure of the death rate of an organism. When *D*-value is determined at 121°C (250°F; typical temperature used for canning), it is often expressed as D_r. *D*-values of several microorganisms exposed to heat treatment are reported later in the chapter, and several *D*-values obtained for bacteria exposed to an irradiation treatment are reported in Chapter 7.

A third term is *Z*-value, which refers to the degree Fahrenheit required for the thermal destruction curve to traverse one log cycle. The *Z*-value provides information on the relative resistance of an organism to different destructive temperatures and allows for calculating equivalent thermal processes at different temperatures (Jay, 2000).

Intrinsic Factors

The intrinsic factors are the ones related to the medium in which the microorganisms grow.

Moisture Content

The amount of moisture in the food determines which microorganisms can grow. It is generally accepted that water requirements of microorganisms are described in terms of water activity (a_w), which is defined by the ratio of water vapor pressure of the medium (e.g., food product) to the vapor pressure of pure water at the same temperature. The a_w of most fresh meats is around 0.99 (pure water is 1.00). The minimum a_w for most spoilage bacteria is 0.91, for most spoilage yeast it is 0.88 and for most spoilage molds it is 0.80. However, it should be realized that there is large variation among bacteria, where *Pseudomonas* requires a_w of 0.97 and *Clostridium botulinum* types A and B require a minimum of 0.94.

One of the oldest methods of preserving meat and other foods is by drying. Meat can be dried by heat (sun, fire, oven) or by salt addition and thereby removing or binding the water. A salt concentration of 3.5% will result in an $a_w = 0.98$, and 16% NaCl will provide an $a_w = 0.90$. In the past, heavily salted meat products were kept for long periods by adding about 15% salt and reducing the a_w to a level where spoilage and pathogenic bacteria could not grow. This practice is still used today in different parts of the world, especially for fish meat. The product must be soaked/washed prior to consumption because of the high salt concentration.

Nutrient Content

Microorganisms require a nutrient content in order to grow, and this can be broadly divided into water, energy source, nitrogen source, vitamins and minerals. Limiting one of those sources can prevent or decrease growth or result in cell death. As indicated above, water content affects the type of microbiota found in the food; molds having the lowest requirement, followed by yeasts, Gram-negative bacteria and Gram-positive bacteria. Most microorganisms utilize sugars as their main energy source, whereas only a few microorganisms can use complex carbohydrates such as starches and cellulose. Fats can also be used by microorganisms as a source of energy, though fat is consumed by a relatively small proportion of microorganisms growing in foods. The primary nitrogen source are the amino acids found in the muscle tissue, but other compounds such as nucleotides and long peptides can also be utilized. In general, simple amino acid compounds will be utilized before microorganisms will attack more complex compounds such as peptides, complex carbohydrates and fats. In terms of vitamins, a certain number of bacteria require B vitamins, but this is usually not a problem for microorganisms growing in meat and meat products. In general, Gram-negative bacteria and molds are able to synthesize most or all of their vitamin requirements. Gram-positive bacteria are the least capable of synthesizing vitamins and must, therefore, be supplied with one or more of these compounds.

Biological Structures

This refers to the natural covering of various foods (e.g., skin on muscles and shells on eggs) that can provide protection against the entry of microorganisms. Outer coverings of fruits and vegetables, the shells of nuts and the testae of seeds also provide a barrier that physically blocks bacteria entry. Once the outer structure is damaged or cracked, the structure inside might be subjected to infection and/or spoilage. During the slaughter operation, the cutting of the skin represents an opportunity for microorganisms to gain entry into the sterile poultry muscle tissue.

Oxidation Reduction Potential

This can be generally defined as the ease with which the substrate loses or gains electrons. When a compound loses electrons, it is said to be oxidized, whereas when it gains electrons, it is reduced. Therefore, a substance that easily gives up electrons is a good reducing agent. When electrons are transferred from one compound to another, a potential difference is created between the two compounds. This can be measured in millivolts (mV), and the more highly oxidized a substance is, the more positive its electrical potential will be. When the concentration of an oxidant and reductant are equal, the electrical potential will be zero. The oxidation reduction potential of a system is expressed by the symbol *Eh*. Anaerobic microorganisms require negative *Eh* values (reduced conditions), whereas aerobic bacteria require positive *Eh* values (oxidized conditions). Among the compounds that help to maintain reduced conditions in meat are the sulfhydryl (SH) groups found in different proteins. Microorganisms that require reduced conditions for growth initiation (usually about −200 mV) are the anaerobic bacteria such as the genus *Clostridium*. Microorganisms that require a positive *Eh* for growth are aerobic bacteria such as the genus *Bacillus*. Bacteria that have the capacity to grow under aerobic or anaerobic conditions are called facultative anaerobes. Overall, microorganisms affect the *Eh* of the environment while they grow. This is especially true for aerobes, which can lower the *Eh* of the environment while anaerobes cannot do it to such an extent. With respect to meat, the *Eh* of muscle just after slaughter is around +250 mV and, after postmortem completion, it falls to around −100 mV. When bacterial growth is allowed to occur, the *Eh* usually falls further and can reach −250 mV (Jay, 2000).

Hydrogen Ion Concentration (pH)

Most microorganisms grow best at neutral pH (around pH = 7.0), and only a few grow below 4.0. Bacteria vary in respect to the minimum and maximum pH in which they can grow; *Salmonella* can grow between pH of 4.1–9.0, *C. botulinum* between 4.8–8.2 and *C. perfringens* between 5.5–8.5. For yeasts and molds, the pH range is much wider (1.5–8.5 and 1–11, respectively). The pH of postmortem meats is around 5.5 and 6.0. This makes it susceptible to bacteria, mold and yeast growth. It is known that meat from fatigued animals (i.e., higher pH; see Chapter 2) spoils faster than meat obtained from rested animals. This is a direct result of the higher ultimate pH that is closer to neutral. In rested animals, glycogen (about 1%) is totally converted to lactic acid and results in a pH drop from neutral to about 5.5–6.0, depending on the muscle. In fatigued animals, most glycogen has been consumed prior to slaughter, the pH drop is less pronounced and, hence, microorganisms can grow more easily in such meat.

In fermented meat products, such as summer sausage and pepperoni, lactic acid bacteria are used to reduce the pH and, hence, increase shelf life. If the pH is low enough, and the a_w has been reduced by drying to about 0.90 or below, the product can be shelf-stable at room temperature.

Different organic acids, such as citric, lactic and acidic acids, are used to marinate a variety of fresh poultry cuts (see Chapter 9). They are used to assist in extending their shelf life, as well as enhancing/creating new flavors. Such products are usually kept refrigerated because the amount of acid added is insufficient to retard the growth of all potential spoilage and pathogenic microorganisms.

Antimicrobial Agents

Direct addition of antimicrobial agents is usually not permitted in most parts of the world. However, some foods have certain naturally occurring substances that can delay or retard the growth of microorganisms. One of the best examples in the poultry industry is the lysosyme found in eggs. This enzyme provides fresh eggs with an efficient antimicrobial system to suppress microbial growth during the incubation of the egg. Fresh poultry meat is not expected to contain antimicrobial agents, unless antibiotic residues are present (i.e., insufficient withdrawal time occurred between administration and slaughter).

Extrinsic Factors

Extrinsic factors relate to the outside environment surrounding the microorganism or, in other words, the storage environment. They include the following:

Temperature

This affects the rate of growth of all microorganisms that can grow over a wide range of temperatures; however, microorganisms are usually divided into three major groups based on their optimal temperature growth:

Psychrotrophs grow well at <7°C and have an optimum between 20 and 30°C. Examples: *Pseudomonas* and *Enterococcus,* which are commonly found in food, can grow at refrigerator temperature and spoil meat. Note: standard plate counts to enumerate psychrotrophs should be conducted at refrigerated temperatures (e.g., 5°C) for about seven days. If incubated at 30°C, mesophiles present in the sample but not responsible for spoilage will grow.

Mesophiles grow well between 20 and 45°C with optimum growth between 30 and 40°C. An example is *Staphylococcus,* which can grow in inappropriately refrigerated food (see discussion on *S. aureus* food poisoning later in the chapter).

Thermophiles grow well at and above 45°C with optimum between 55–65°C. Examples of bacteria of importance in food belong to the genera *Clostridium* and *Bacillus*. Although only a few species of these genera are thermophilic, some are spore forming and, therefore, of interest to food scientists working with cooked and canned foods.

Controlling storage temperature is one of the most important parameters used to prolong the shelf life of meats. Figure 11.8 shows the effect of storage temperature on the rate of spoilage microorganisms' growth. It can be seen that the rate at 10°C is about twice that at 4.5°C, and that at 15.5°C is about four times that at 4.5°C for both the high and low initial contamination levels.

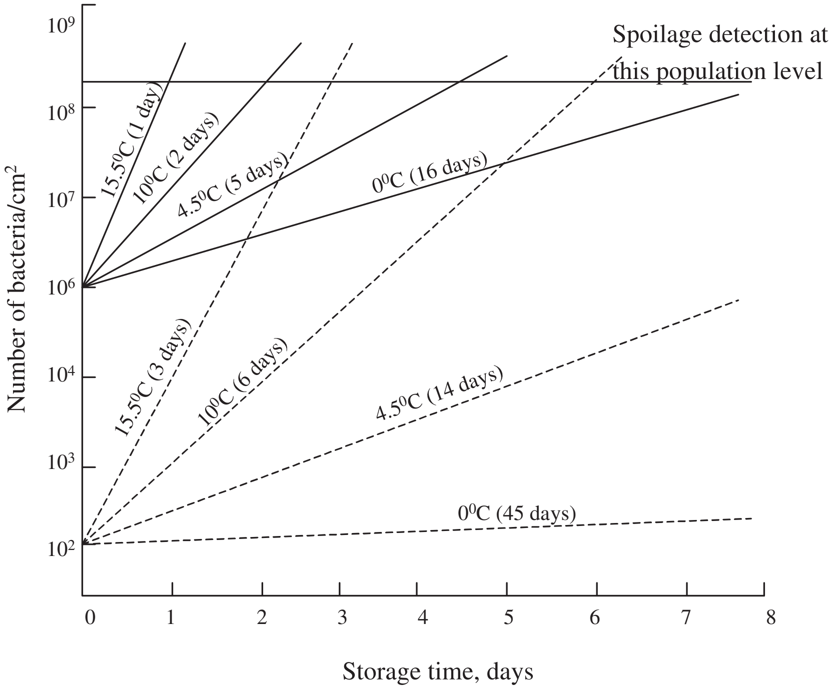


Figure 11.8. *The Time Required for the Spoilage of Frankfurters that Were Contaminated with High and Low Levels of Psychrophilic Bacteria. Spoilage Detection (by Slime Formation) Was at a Population Level of 150 Million Bacteria/cm^2 of Surface Area. The High Level of Contamination Was 1 Million/cm^2, Shown by the Solid Line; the Low Level Was 100 Bacteria/cm^2, Shown by the Broken Line. Adapted from Zottola, 1972.*

Relative Humidity

The storage environment affects the growth of microorganisms at the surface and inside the food as it affects the overall a_w of the food. Actually, the relative humidity of a packaged/sealed environment can be expressed based on the water activity of the food ($a_w \times 100 =$ relative humidity). Improperly packaged fresh poultry meat, stored in a refrigerator, tends to undergo surface spoilage even before deep muscle spoilage occurs, primarily due to surface condensation (i.e., high relative humidity in the refrigerator). Drying of food products is an old method of preservation that suppresses microbial growth by removing available moisture. However, when drying the meat to such an extent, textural changes should be expected. Partial drying of meat products is applied during manufacturing of semidry and dry fermented sausages (e.g., salami, summer sausage) dried at RH of about $80 \pm 5\%$. This results in reducing the a_w to <0.90 and making the product shelf stable when combined with low pH obtained by lactic acid fermentation.

There is a relationship between temperature and relative humidity that should be kept in mind when selecting a storage environment. Overall, increasing the temperature of a given mass of air will result in lowering the relative humidity (i.e., the saturation point of warmer air is higher than cold air). In general, bacteria can grow at relative humidity $>92\%$, yeast at $>90\%$ and mold at >85–90%.

Gas Type and Concentration

The atmospheric environment surrounding the food can be modified to prolong the shelf life of the product. As indicated before, microorganisms can be divided according to their requirements for oxygen. Aerobic bacteria such as *Pseudomonas* require oxygen to grow, while anaerobic bacteria such as *Clostridium botulinum* grow without oxygen. Facultative microorganisms such as *Lactobacillus* can grow either in the presence or absence of oxygen.

The storage of food in packages containing a different gas mixture than the normal atmospheric composition is referred to as modified atmosphere (MA) or controlled atmosphere storage. The most common MA for meats is an elevated CO_2 concentration. This method has been developed along with the use of vacuum packaging (removal of all air from the package) (Genigeorgis, 1985). The inhibitory effect of CO_2 increases with decreasing temperatures, primarily due to the higher solubility of CO_2 at lower temperatures. This results in carbonic acid formation that slightly lowers the pH compared to meat stored under air. Gram-negative bacteria are more sensitive to CO_2 than Gram-positive bacteria. *Pseudomonas,* which is one of the main spoilage bacteria, is sensitive to elevated CO_2 concentration, while lactic acid bacteria are more resistant. The shelf life of fresh chicken quarters was reported to be ex-

Table 11.1. Example of Factors Used to Extend the Shelf Life and Improve Safety of a Cooked Turkey Sausage such as Bologna/Frankfurter (i.e., the Hurdle Concept).

Step	Comments
Production	
Low initial microbial count Fresh meat kept at a low temperature Short storage time	Start with the cleanest possible raw meat to minimize microbial growth and processed quickly so as not to allow excessive bacteria growth
Processing	
Nitrite	Added at 100–200 ppm mainly to inactivate *C. botulinum* (Note: the product is only heated to 70–75˚C so the spores cannot be destroyed by heat.)
Salt	At the level added (1.5–2.5%), some reduction in a_w and some general antimicrobial activity
Lactate	Permitted in some countries as an antimicrobial agent
Equipment	Should be kept clean to reduce risk of cross contamination. Also, schedule cleaning and sanitizing intervals throughout the day
Cooking	Heating to 70–75˚C destroys most pathogens and spoilage bacteria, but if the product is left unrefrigerated, it will spoil within 12–48 hours, meaning that viable bacteria are still present
Packaging	Prevents re-contamination
People	Keep hands clean, hair nets, clean clothing. Do not let sick people handle food
Storage and Distribution	
Low temperature	In storage coolers, trucks, retail stores, home refrigerators
Package kept intact	Keep package intact

tended up to 35 days at 2°C when packaged under 60–80% CO_2 (Hotchkiss et al., 1985). The packaging material used should consist of a good grade oxygen and CO_2 barrier in order to preserve the MA conditions in the package. It should be mentioned that the color of the myoglobin will be affected by the lack of oxygen, and meats with high pigment content (e.g., dark leg meat) will be changed to brown color under “low oxygen” conditions. This is a reversible transformation, and at the retail store, the meat can be removed from a high CO_2 bulk package and displayed under normal oxygen concentration (20%). The oxymyoglobin red color should return within an hour or so (see Chapter 13).

Presence of Other Microorganisms

This is often referred to as “bacterial interference,” meaning that some microorganisms can produce substances that are inhibitory or lethal to others. The substances can include antibiotics, organic acids, hydrogen peroxide and bacteriocins. Some of the classical ones in the area of food science include yeast, which produces alcohol that suppresses bacteria growth in wine, and the inhibition of mold in Swiss cheese by *Propionibacter*. In fresh meats, the suppressive effect of the natural microflora on *C. botulinum* growth is well established. The commercial “Wisconsin Process” has been designed to innoculate vacuum-packaged products, such as bacon and ham, with lactic acid bacteria that would grow in cases of abused temperature conditions, would produce acid and would suppress *C. botulinum* growth.

Interaction of Factors (The Hurdle Concept)

Quite a few of the poultry products presented to the consumer at the retail level are preserved by a combination of different factors. An example is a cooked turkey sausage such as bologna or frankfurter (Table 11.1).

As previously discussed, temperature is one of the most important factors in extending the shelf life of stored fresh meat that does not contain any additives. Figure 11.8 illustrates the importance of storage temperature and of processing the meat under hygienic conditions to obtain the lowest possible initial microbial counts.

ASSESSING THE NUMBER OF MICROORGANISMS

Evaluating the number and type of microorganisms present in poultry meat is the basic work of the food microbiologist. Different methods have been developed, however, none permits determining the absolute exact number of microorganisms in a food sample. Although some methods are better than others, every method has certain inherent limitations (Jay, 2000).

The basic methods used to estimate the “total” number of microorganisms are the standard plate count, direct microscopic count, the most probable number, membrane filter, dye reduction and surface sampling. There are also physical (e.g., impedance, microcolorimetry and flow cytometry), chemical (e.g., radiometry, thermal-stable nuclease, lux gene luminescence), molecular (e.g., DNA amplification, restriction enzyme analyses, pulsed field gel electrophoresis) and immunological methods (e.g., fluorescent antibody, ELISA, radioimmunoassay).

In this chapter, the basic and most commonly used method will be described. Reference to more advanced methods, usually performed by special microbiology laboratories, can be found in Jay (2000) and other microbiology textbooks.

Conventional Sampling Methods

Standard Plate Count (SPC)

SPC is, by far, the most commonly used method for determining the numbers of viable colony-forming units (cfu) in food. For this method, a portion of a food sample is blended/homogenized and serially diluted (Figure 11.9).

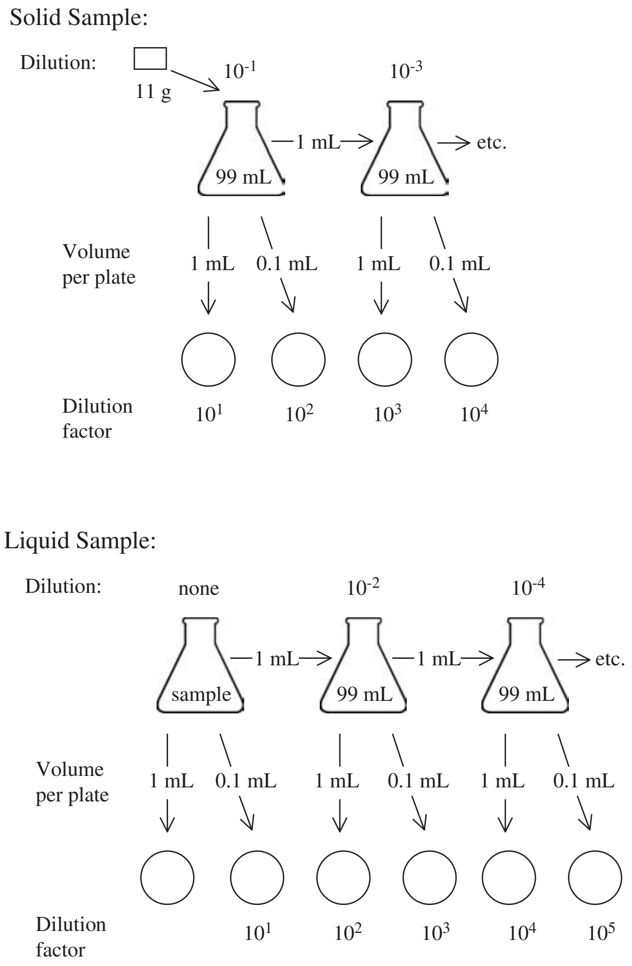


Figure 11.9. *Examples of Dilution Schemes for Solid (Meat) and Liquid Samples.*

A portion of each dilution is plated in or onto suitable agar growth media and is later incubated at a predetermined temperature for a given period of time. Later, all the visible colonies are counted manually or by an electronic counter. The assumption is that each cell produces one colony, and therefore, the number of colonies, in the appropriate dilution, is used to express the number of cells (per gram, cm^2 or ml) in or on the sample. An appropriate dilution plate is considered to be a plate showing between 25 to 250 colonies. Plates showing over 250 colonies are considered "too numerous to count" accurately and are not counted because of overcrowding and potential difficulty in counting overlapping colonies. An "estimated" count can be determined from overcrowded plates when no other plates (with a colony count between 25–250) are available.

The SPC is commonly determined by pour plating, which provides essentially similar results to surface plating (i.e., solidified agar plates are prepared ahead of time, and usually a 0.1 ml inoculum is distributed over the agar surface with the aid of a plate spreader). Surface plating provides the advantage of enumerating heat-sensitive psychrotrophs, which do not come in contact with the hot melted agar. It is also used for enumeration of aerobic organisms whose growth may be restricted if embedded inside solidified agar. The SPC method allows different selective media to be used for presumptive identification.

One of the most important points in microbial counting is to obtain a representative sample of the food. This requires proper sampling (e.g., collecting 10 samples of 25 g each from a "meat combo") and adequate blending/homogenizing of all samples. One of the most popular ways to achieve good mixing is to use a Stomacher Laboratory blender, which was developed in England. This is a fairly simple device that homogenizes the sample (e.g., 10 g of meat in 90 ml of a sterile peptone solution) placed in a strong sterile plastic bag by the vigorous pounding of two paddles. This usually shears the food, and the microorganisms are released into the diluent. Some of the advantages of using a Stomacher over the original blender jar method are no heat buildup during the process and no need to wash, prepare and autoclave blender jars. The homogenates are sampled the same way as in the conventional blender jar (Figure 11.9) and, in addition, the samples can be stored and frozen in the same bags. Recently, specialized bags with an interior filter that separates fat from the liquid of a meat sample (i.e., eliminate pipetting of some of the fat) have been introduced.

Samples of the homogenate can be manually plated or plated with the use of a Spiral Plater. The latter is a mechanical device that distributes the homogenate over the surface of a rotating plate containing solidified agar. The dispensing arm moves from the center of the plate toward the exterior edge, depositing the sample in an Archimedes spiral. This is done by an automated system that continuously decreases the volume of the sample, so that a concentration range of up to 10,000:1 can be plated on a single plate. The enumeration of the colonies (counted after suitable incubation) is done using a special counting grid (Figure 11.10). Some of the main advantages of this technique are the need for fewer agar plates and pipettes, the preparation of less sample dilutions and less labor. One of the problems with the equipment may be associated with food particles that can block the dispensing system, so careful monitoring is required.

A convenient modification of the traditional glass/plastic plates is the newer dry film that consists of two plastic films attached on one side and coated with a culture media and a cold, water-soluble gelling agent. One such popular commercial product is the so-called Petrifilm® that comes sterile and ready to use. Sampling is done by placing a 1 ml diluent between the two films. The diluent is spread to a certain area using a specialized "spreader." An example of a nonselective film is the aerobic colony count film which, after inoculation, shows red colonies on the film. The change in color is due to the presence of tetrazolium dye included with the nutrients. The film can also be prepared with a selective ingredient(s) for counting specific bacterial groups. The film method is an acceptable alternative, approved by AOAC, to the standard plate count method that employs petri dishes.

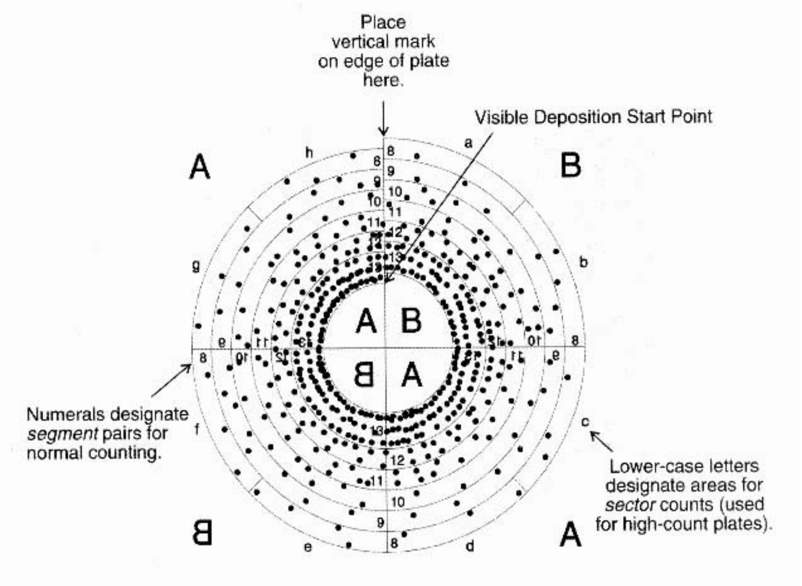

Place vertical mark on edge of plate here.
Visible Deposition Start Point
A
B
B
A
a
b
c
d
e
f
g
h
8
9
10
11
12
13
A B
B A
Numerals designate *segment* pairs for normal counting.
Lower-case letters designate areas for *sector* counts (used for high-count plates).

Figure 11.10. *A Special Counting Grid Used for a Spiral Plater. The Instructions Indicate "Place the Plate on the Counting Grid So that the Deposition Start Point is at the 12 O'Clock Position. On High-Count Plates, the Deposition Start Point is Visible to the Eye; on Low-Count Plates, Use the Vertical Line Marked on the Edge of the Plate." Courtesy of Spiral Biotech Inc., Norwood, MA, U.S.A.*

Conventional Membrane Filters

These are used for liquid analyses, such as water and liquified food samples. Usually, a filter with a pore size of 0.45 µm is used to strain a predetermined volume of liquid. Later, the membrane is placed on a solidified agar plate or a pad saturated with a culture medium and is incubated. Alternatively, a direct microscopical count can be used following an appropriate staining and a treatment rendering the membrane transparent. This method is quite popular for water sampling, where a fluorescent dye and an epifluorescent microscope are used to view and count the cells. This is used as a rapid method that can yield results within 0.5 hour.

A procedure using a hydrophobic grid membrane filter has also been developed to enumerate microorganisms from liquid or liquified food samples. The filter is constructed from about 1,600 wax grids, on a single membrane, that restricts growth and colony size to individual grids. Also, in this case, all cfu can be enumerated or, if selective media is used, specific groups such as *Salmonella* and *Pseudomonas* can be counted.

Most Probable Numbers (MPN) Technique

This technique represents a statistical method where three serial aliquots or dilutions (prepared as for the standard plate count) are plated into nine or 15 tubes of an appropriate medium for the three- or five-tube method, respectively. The number of microorganisms in the food sample are determined by the use of standard MPN tables. The method is commonly used to enumerate specific microorganisms (e.g., *Clostridium botulinum*) that can be determined using an appropriate selective media. The main advantages of this method include its simplicity and ease of performance. In addition, when comparing results from different laboratories, the numbers obtained are more likely to agree, compared to the standard plate count method (Jay, 2000). The MPN is usually the method of choice for enumerating fecal coliforms. Among the disadvantages are the lack of opportunity to observe colony morphology and the use of a large volume of test tubes.

Dye Reduction

Dye reduction is used to estimate the number of viable microorganisms in a food sample. The time for the dye to change color is inversely related to the number of microorganisms in the sample. Two dyes are commonly used: methylene blue which changes color to white and resazurin which changes color from light blue to pink/white. The test is conducted by adding a properly prepared supernatant of the food sample to a standard dye solution. Various raw and ground meat samples have been successfully evaluated by the resazurin reduction method, with which a raw meat sample with 10^7

bacteria/g could be evaluated within 2 hours. The main advantages of this method are its low cost and speed and the fact that only viable cells reduce the dye. Some of the disadvantages are related to the fact that not all microorganisms reduce the dye equally.

Direct Microscope Count

This is a simple form of counting microorganisms on a smear of a food sample or a culture. The fixed microscope slide has to be stained with an appropriate dye and then viewed with a light microscope (usually high magnification with an oil emersion objective is used). Some of the advantages of this method include its speed and simplicity and that cell morphology can be examined. Some of the drawbacks include the fact that food particles can sometimes be mistaken for bacteria, the microbial cells are not always uniformly distributed within the smear, some cells that do not stain well may not be counted and counting is done on viable and nonviable cells. However, it is the fastest way to assess the microbial numbers in a food product.

Swabbing or Swabbing and Rinsing

These are the most commonly used methods for surfaces in contact with food and/or meat surfaces (e.g., poultry skin). A cotton swab is used to rub a specific area defined by a template (e.g., 1, 10 or 100 cm^2). The sterile swab, which can have a dry or a wet tip, is rubbed in different directions, thoroughly covering the area. The swab is then returned to its holder/test tube that contains the diluent. The microorganisms can then be enumerated by a method such as the standard plate count. One of the limitations is that the operation does not recover all the microorganisms from the surface. However, consistent use of the method can provide valuable information, as long as one realizes that not all microorganisms have been recovered.

A new innovation is the use of the bioluminescent technique, where a swab is dipped into a chemical solution that ruptures the cell's membrane. The ATP (the "energy" molecule) is released from the cell and reacts with a light-producing compound (Figure 11.11). The amount of light can be read in a special spectrophotometer that can be a small, handheld unit. The reading

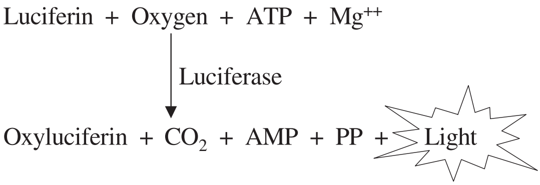

Luciferin + Oxygen + ATP + Mg^{++}
Luciferase
Oxyluciferin + CO_2 + AMP + PP + Light

Figure 11.11. *The Reaction of the Firefly Luciferin-Luciferase System; ATP and AMP Are Adenosine Tri-and Monophosphate, Respectively.*

obtained can be calibrated against a standard plate count reading. This is an extremely rapid method (results within 1–2 minutes) that is currently used to assess sanitation practices in a poultry processing plant. (See more discussion on the bioluminescent later in the chapter.)

Contact Plates

A contact plate, also known as the replicate organism direct agar contact (RODAC), uses special petri dishes with raised agar surfaces. The plates are pressed against a surface and later incubated and counted. The method can be easily used on smooth, nonporous, firm surfaces. It is not suitable for heavily contaminated surfaces because no dilution is applied. However, when used for monitoring a surface that has been cleaned and sanitized, the numbers should be low and the sampling adequate. It should be remembered that when surfaces have been cleaned with certain detergents, it may be necessary to include a neutralizing agent in the media to prevent suppression of microbial growth. An "agar sausage" or an "agar syringe" are two modifications of the RODAC method. Basically, the agar is made into a sausage shape and, after each sampling, a slice is cut off and placed in a petri dish for incubation.

Physical, Chemical and Molecular Methods

Physical methods are used to estimate the number of cells or quantity of the by-products produced by the cells. Most physical and chemical methods follow the metabolic activities of microorganisms or measure a growth response. One of the main advantages is speed. This is very important because fresh poultry meat is usually shipped to the market within 24 hours; whereas, the traditional standard plate count method requires 48–72 hours to obtain a result. By that time, the meat may have already been purchased. Therefore, the food industry is continually looking for new rapid methods to estimate bacteria numbers and identify pathogens. Detecting a specific pathogen such as *Salmonella* may require a week when using traditional methods. Physical methods such as impedance have been shown to be effective in rapidly assessing the bacteria numbers within 12 hours or less.

Impedance

When bacteria grow and multiply, they consume nutrients consisting of large molecules, and break them down into smaller compounds. These compounds change the impedance (the opposition of an alternating electrical current to flow in a conducting media). When the microbial population reaches a level of 10^6–10^7 cells/ml, a change can be observed as a decrease in impedance. The time required for this change is known as the impedance detection time (Firstenberg-Eden, 1983). The impedance curves are reproducible for certain species and strains, and mixed cultures can be identified by using a specific growth inhibitor (Jay, 2000). The method has been shown to be capable of detecting as few as 10–100 microorganisms. Commonly, a cell population of 10^5–10^6/ml can be detected within 3–5 hours, and 10^4–10^5/ml within 5–7 hours (i.e., these times are the periods required for the organism to reach a threshold level of 10^6–10^7 cells/ml).

It is important to remember that when using impedance methods, the fastest growing bacteria or group of bacteria in the sample will cause the change in impedance (depending on temperature, substrates, etc.). When evaluating total aerobic plate counts, all bacteria are able to reach a visible biomass and later be counted. To selectively encourage a certain group, substrate, incubation temperature and time can be modified. An example would be a mixed sample containing one coliform and 10^5 of a psychrotrophic *Pseudomonas*. If the sample is incubated at 35°C, the coliform will be the bacteria responsible for the change in impedance because its generation time is four times shorter than the *Pseudomonas*. In the same manner, selective media can be used to enumerate one group or genus of bacteria present in a mixed sample. The most common way of using impedance is to determine if a sample contains above or below a certain number of bacteria. This is done by comparing results from a new sample with a calibrated curve obtained by comparing impedance detection time and conventional total plate count (usually 100 samples are employed to construct the calibration curve). This approach has been used to determine the number of bacteria in foods such as meat, frozen vegetables, raw milk and fish (Firstenberg-Eden, 1983). Selective media have also been used to enumerate groups such as fecal coliforms. Generally speaking, if a particular species of bacteria is identified to grow on temperature-abused broiler carcasses, it can be used as an indicator of temperature abuse instead of measuring the growth of all mesophilic bacteria (Cox et al., 1998).

Adenosine-Triphosphate (ATP) Measurement

This method is based on the fact that ATP is the primary source of energy in all living organisms, and it can be used to monitor the presence of live bacteria. Today, there are easy-to-use commercial kits for rapid measurement of the ATP present in a given sample and estimation of the number of microorganisms present. One of the common ways to quantify the amount of ATP is to use the firefly luciferin-luciferase system (Figure 11.11). Luciferase will emit light in the presence of ATP, and the amount can be measured with a liquid scintillation spectrophotometer or a luminometer. The amount of light produced is proportional to the amount of ATP present in the sample. An example of a correlation curve is provided in Figure 11.12, where conventional plate counting was plotted against light emitted.

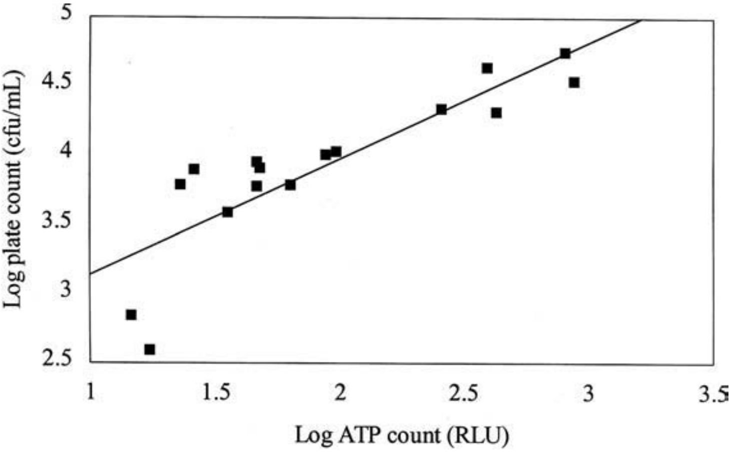


Figure 11.12. *Relation between Adenosine Triphosphate (ATP) Bioluminescence and Plate Count for Determining the Microbial Load in 16 Samples of Poultry Processing Water. From Bautista et al. (1994). With Permission.*

The application of this method has enabled the development of a rapid method (1–3 minutes) to enumerate microorganisms and is commonly used for quality control purposes. One such application is swabbing, followed by dipping the swab in a commercial enzyme/luciferase solution and reading the amount of light emitted. This can be used to monitor the hygiene of surfaces in contact with food. It should be mentioned that this method works very well in further processing plants where postmortem meat is used (i.e., all the muscle cells' ATP has been depleted). In the live bird processing areas, ATP from the animal cells might contribute to the light emitted during the test. Overall, most of the ATP within the muscle cells will be depleted within 1–2 hours after slaughter. In any case, monitoring the cleanliness of surfaces after a scheduled cleaning should show no indication of living cells of any type. The system has been used successfully to monitor the efficiency of a hazard analysis critical control point (HACCP) program in poultry processing plants (see Chapter 12). The results are obtained in less than 5 minutes and can be used to quickly point out a problem area, which may contribute to cross contamination, and to correct it immediately.

Other Advanced Microbiological Detection Methods

There are numerous sophisticated methods used to quantify and fingerprint microorganisms in food samples. These methods are very important in monitoring and tracing problems associated with contamination (i.e., linking a foodborne outbreak to a specific product); however, it is beyond the scope of this book to describe all of these procedures. Methods such as nucleic acid probes, polymerase chain reaction, restriction enzyme analyses, pulsed field gel electrophoresis, random amplification of polymorphic DNA, ribotyping and the lux gene luminescence technique can be found in Jay (2000) and other microbiology textbooks.

POTENTIAL CONTAMINATION SOURCES DURING POULTRY PROCESSING

Growing

Live poultry entering a processing plant carry natural diverse, microbiota, most of which are not pathogenic to humans. This is a result of the common practice of raising poultry on litter floors, exposure to the natural environment and some contact with wildlife (e.g., birds, mice). Poultry can carry some human pathogens such as *Salmonella* and *Campylobacter*. Only occasionally do young poultry show symptoms of bacterial infection resulting from the above-mentioned bacteria, and, in most cases, they are healthy carriers of these pathogens. In some countries, such as Sweden and the Netherlands, comprehensive *Salmonella* reduction/eradication programs have been performed. They include monitoring of parent and grandparent breeder stocks as well as the large, growing farms. Breeder stocks testing positive for *Salmonella* have been eradicated, and regular flocks have either been eradicated or slaughtered under special arrangements. This is a fairly expensive route, and most other countries have not followed it to such an extent. However, it should be mentioned that monitoring breeder stocks is a common practice around the world, and this practice, along with others, such as competitive exclusion (described below), are employed to reduce *Salmonella* contamination. The goal of the industry is to reduce the total number of microorganisms in order to ensure an adequate shelf life during distribution and to minimize cross-contamination problems associated with pathogens. In this field, the poultry industry is not different from the red meat industries fighting the same battle. Spoilage microorganisms mainly include psychrotrophs such as *Pseudomonas,* lactic acid bacteria and yeasts that are present on the birds (Table 11.2).

Competitive exclusion (CE) has been one of the new approaches to *Salmonella* control at the farm level. This procedure is based on the recognition that newly hatched chicks are highly susceptible to *Salmonella* infection because they have been produced in a strictly sanitized environment (i.e., hatchery). Because the chicks have no contact with parent birds and are slow to develop an intestinal microflora that could successfully compete with ingested pathogens, they are very susceptible. Nurmi and Rantala (1973) were among the first to suggest a means of establishing an adult-type gut microflora in chicks by dosing the birds orally with suspensions of anaerobic cultures of

Table 11.2. Microflora of Poultry Carcasses Immediately after Processing. Adapted from McMeekin and Thomas (1979).

Year of Study	1966	1976	1978	1979
Organism				
Micrococcus spp.	50[a]	—	30	3
Gram-positive rods	14	<10	—	4
Flavobacterium	14	20	18	8
Enterobacteriaceae	8	—	8	8
Pseudomonads	2	<10	26	5
Acinetobacter/Moraxella	7	50	4	65
Yeasts and others	5	<10	14	7
Ratio of motile/nonmotile bacteria	26/74	30/70	48/52	21/79

[a] % isolated.

—, not analyzed.

gut contents from adult, *Salmonella*-free poultry. In this way, the treated chicks became resistant to an oral challenge of about 10^6 *Salmonella*/bird. Overall, the protective effect is not significantly influenced by the breed, strain or sex of the bird, but it depends upon the introduction of viable bacteria, especially anaerobes (Mead, 2000). Although attempts have been made to identify the protective bacteria and to develop preparations of known composition, these are generally less protective than anaerobic cultures or suspensions of gut content and, over time, tend to lose their protective capability. Therefore, a large number of available preparations on the market are based on the original approach of undefined cultures of cecal material. It is necessary, however, to screen the preparations rigorously to ensure the absence of all relevant avian and human pathogens. Overall, it has been a lengthy process to get approval for such a procedure and, in practice, CE treatments are used in two ways. The first is for newly hatched chicks that are spray inoculated in the hatchery. The birds are wetted on the upper part of the body, and ingest treatment organisms while preening themselves. The second method is applicable to older birds, usually breeding stock, that are already *Salmonella* carriers and require an antibiotic therapy to eliminate the infection. The therapy is followed by administration of a CE preparation via the drinking water to prevent reinfection. The effect of CE treatment on *Salmonella* entering the gut is largely to prevent its growth, so that *Salmonella* is gradually eliminated. However, the exact mechanism of protection is unclear and is likely to be influenced by factors such as pH and Eh, inhibitory substances such as H_2S, bacteriocins and competition for receptor sites (Mead, 2000). Competitive exclusion must always be combined with good husbandry hygiene because, while the protective flora is becoming established, the chicks will remain susceptible to infection. Also, any infected chick is a potent source of infection for its cohorts and, with little microbial competition in its intestines, will commonly shed 10^7–10^8 *Salmonella* per g of feces for other chicks to acquire. Such a large challenge is capable of overcoming the protection offered by CE treatment.

Competitive exclusion treatment has been routinely used in Sweden for a number of years, showing no adverse effects on bird health or growth performance; therefore, it is seen as an important part of the broiler control program. In trials carried out in other countries, especially the Netherlands, the treatment has reduced the number of *Salmonella*-positive flocks and the proportion of birds within flocks that become infected. In the United Kingdom, commercial use of CE is mainly confined to breeder flocks, at present. Where CE treatment is to be part of a control strategy, *Salmonella*-free chicks are a necessary starting point, because the treatment is a prophylactic and cannot be expected to eliminate existing *Salmonella* in the flock.

Transportation

Transportation refers to the operation of catching and moving the birds to a processing plant. The catching operation may be manual or mechanized, and the transport coops may consist of hard-to-clean wooden crates or more washable metal and plastic cages (see Chapter 3). Minimizing bruising and injury to the birds during the loading and unloading operations is an important step in reducing cross contamination among birds that are already under stress (i.e., birds are usually taken off feed and water prior to leaving the farm). Stress during transportation is known to cause changes in excretion patterns due to disturbance of intestinal function. Excretion of pathogens, such as *Salmonella,* can cause cross contamination among birds within the same cage or in cages located underneath. Therefore, proper cage design (to prevent fallout of fecal material while allowing adequate ventilation) and cleaning and sanitation of the cages are very important (see improved cage design; Figure 3.2). Cleaning and sanitation is much easier when plastic or metal cages are used, mainly due to the smoother surface compared to wood. Modern poultry processing plants usually employ a rigorous cleaning and sanitation process of the crates after each trip to the farm in order to minimize *Salmonella* and other bacterial cross contamination from a previous flock. The principles of proper cleaning are described later in the chapter and include thorough removal of all organic matter from the surface (can be done by physical force, including scraping or high-pressure water jet) followed by chemical means (detergents), proper rinsing and a final disinfection step that should only be applied to a clean surface.

Processing Plant (General)

The operation inside a poultry processing plant is fairly complex (Figure 4.1) and is usually performed at a fairly high speed. This might provide opportunities for a high rate of cross contamination if attention is not paid to proper equipment design. Like in other food processing operations, people working in a poultry plant should exercise caution and try to minimize contamination (e.g., wear clean clothes and hairnets, use hand-washing stations and footbaths). Suggested critical control points (CCP) that can affect the microbiological quality of the meat are described in Chapter 12. Overall, cross contamination may result from repeated contact with processing equipment, bird-to-bird contact, use of a common water bath for scalding and chilling, handling the meat and contact with tools such as knives. Good manufacturing practices as well as an adequate HACCP program can lead to reduction in cross contamination and result in meat with an extended shelf life as well as a lower risk of pathogenic bacteria. Overall, birds can carry external microorganisms that are present on the surfaces of feathers, skin and feet, and are associated with attached soil, fecal material and dust. Internal microorganisms are present, for most parts, in the intestinal tract and respiratory system.

Bleeding and Scalding

The bleeding operation is commonly performed after stunning (except when religious laws such as Kosher processing prohibit the practice). At this point, all or part of the neck blood vessels are ruptured by a machine or manually. In both cases, microorganisms can be transferred from the skin and feathers via the knife/blade into the bloodstream that, in healthy birds, is virtually free of microorganisms. Even though most blood flows outward, some returning blood can carry microorganisms that will be deposited in muscles and other organs. Therefore, care should be taken to maintain this operation as clean as possible.

The scalding operation is used to loosen the feathers and make their removal easier (see Chapter 4). The process is usually done in a scalding tank, which consists of one or a series of water baths, kept at a temperature of 50–63°C. Scalding temperature and time (usually 1–3 minutes) can affect the amount of microorganisms present on the skin when exiting the scalder. Several researchers have reported that scald water contains an aerobic bacterial count of about 50,000 microorganisms per ml. Usually, an initial increase is seen at the start of the day, but later, the number remains relatively constant throughout the processing (Bailey et al., 1987; Young and Northcutt, 2000). Although the external surfaces of the incoming carcasses are contaminated, the destruction of some bacteria by heat, the introduction of fresh, clean water and the continuous overflow of contaminated scald water, prevents excessive buildup of bacteria in commercial scalding tanks. There is an opportunity for microorganisms to be transferred from one bird to another and cause cross contamination, but that usually does not result in a significant difference in the nature or degree of contamination in birds from the same flock. The total bacteria count on broiler skin just after scalding is usually less than 10,000/cm^2 (Bailey et al., 1987). Psychrotrophic bacteria are present on the skin, feathers and feet of live birds (most common are *Achromobacter, Corynebacterium* and *Flavobacterium*), but their numbers usually decrease after scalding. There is a potential for some scald water, in a conventional immersion system, to enter the trachea and contaminate the lungs. The degree of such contamination is less when using a Kosher cut, when bleeding time exceeds 2 minutes, and when birds are electrically stunned (Bailey et al., 1987).

Overall, the scalding operation can have a negative effect on the carcass microbial quality, because carcasses with a high organic matter load are submerged in a common water bath. Therefore, companies designing scalders have searched for alternative methods to improve this situation. A few suggestions have been evaluated over the years and include spray scalding with steam or hot water, employing a countercurrent flow of water in the scalding tank and developing a multistage scalding system. Using spray scalding was found to not be a feasible alternative, mainly because of the high line speeds. Using a countercurrent flow in a single (long) scalder has not been reported to be a practical option because efficient mixing of the water can result in an even distribution of the bacteria along the whole tank. Using a multistage scalding system, consisting of several tanks, was reported to reduce the aerobic counts found on broiler carcasses (Cason et al., 1999). By using a series of tanks (2–4) such as shown in Figure 11.13, the processor can achieve a sequential reduction in the amounts of suspended organic and inorganic solids, as well as aerobic counts present in the scalding water (Table 11.3). The data also indicates that although the scald water in the three-tank system was significantly lower compared to the control (3.85 vs. 4.96 $\log_{10}$

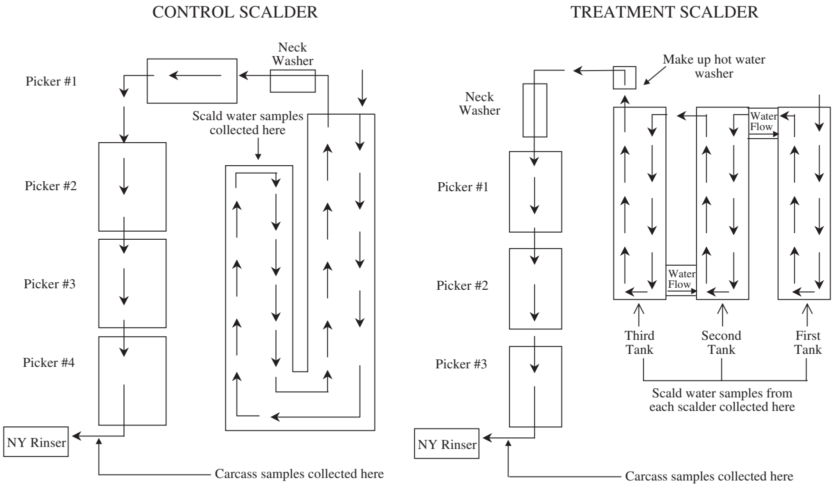


Figure 11.13. *Diagram of Two-Pass, Single-Tank Scalder (Control) and Two-Pass, Three-Tank Counterflow Scalder (Treatment) Installed on Adjacent Slaughter Lines in a Broiler Processing Plant. From Cason et al. (1999). With Permission.*

Table 11.3. Mean of Most Probable Numbers ($\log_{10}$ MPN ± SEM), Estimates of Aerobic Bacteria in Water Samples (per Milliliter) and Total Suspended Solids (g/L) from Each Tank of a Three-Tank, Two-Pass, Counterflow Scalder and from a One-Tank, Two-Pass Scalder (Control) and from Whole Carcass Rinses of New York-Dressed Carcasses Sampled Immediately after Defeathering (per Carcass). Adapted from Cason et al. (1999).

Scalder Type	Tank	Aerobic Bacteria (per ml Water)	$P < F$[a]	Aerobic Bacteria on Picked Carcasses	Suspended Solids (g/L ± SEM)	Suspended Solids $(P < F)$[b]
Counterflow	1	4.61 ± 0.36	0.1598	—	5.12 ± 0.70	0.0001
	2	5.07 ± 0.44	0.0290	—	2.48 ± 0.52	0.0505
	3	3.85 ± 0.38	—	7.77 ± 0.18	1.04 ± 0.29	—
Control	1	4.96 ± 0.41	0.0455	7.71 ± 0.20	3.46 ± 0.50	0.0018

[a] Probability that mean is different from value for Tank 3, determined by orthogonal contrasts.

[b] Probability of a significant difference from Tank 3.

cfu/ml), the carcass rinse counts were not significantly different. However, the significant reduction in suspended solids (3.46 to 1.04 g/L; Table 11.3) and aerobic colony counts of the scald water can assist in obtaining cleaner birds.

Another suggested improvement was to change the countercurrent flow and use a post-scald hot water rinse cabinet (240 ml of 60°C water spray at 40 psi/bird; water then collected and sent to the scalder). The results (Figure 11.14) indicate a reduction in all bacteria groups checked at the pre-chill (after scalding) stage of the 250 carcass rinse samples collected at the three sites

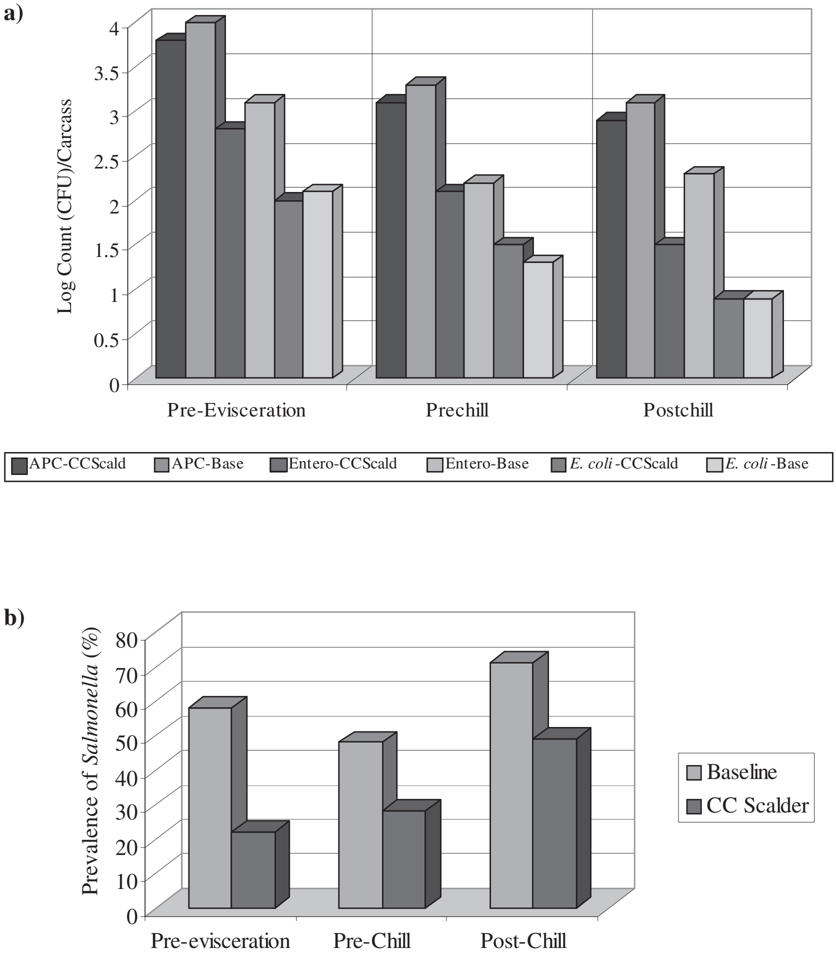


Figure 11.14. *Microbial Counts after Employing a Countercurrent Scalding Operation, Followed by a Post-Scald Hot Water Rinse (a) and Prevalence of Salmonella (b). Legends: APC = Aerobic Plate Count, Entro = Entrobacteriaceae; CC Scald = Countercurrent Scalding and Post-Scalding Spray. From Data by James et al. (1992).*

over a seven-day period. However, the percentage of *Salmonella*-positive carcasses slightly increased due to cross contamination. Overall, scalding resulted in lowering the microbial load in both the modified and baseline processes.

Several reports, but not all, indicate that the shelf life of birds scalded at high temperatures (above 58°C) is reduced. This may be associated with changes to the epidermal layer of the bird's outer skin. A temperature of >58°C can result in removing the cuticle during the subsequent mechanical feather picking (i.e., due to the rubbing action of the fingers), whereas semi-scalding at around 52°C does not damage the cuticle. The cuticle-removed skin of the hard scalded birds apparently serves as a more suitable substrate for spoilage microorganisms (e.g., *Pseudomonas*). It should be mentioned that when a scalding temperature of about 58°C is used, the skin must be kept moist to prevent discoloration; thus, water chill is commonly used. However, when sub-scalding is used (52–54°C), the skin can dry without discoloration, and the birds can be air chilled. Slavik et al. (1995) used 52, 56 or 60°C for chicken carcass scalding and found that *Salmonella* and *Campylobacter* counts can be affected by scald temperature (Table 11.4) resulting from removal of the epidermis at the higher temperature (60°C).

Defeathering

Plucking of the feathers is usually a fully automated process commonly done on-line. Manual and batched-type (i.e., carcasses placed in a rotating drum in which rubber fingers stick out from the sides) are not commonly used in large processing plants but can represent the same microbiological challenges experienced with an on-line automated process. One of the main problems is cross contamination caused by the rubber fingers coming in contact with all the birds passing by. In addition, the conditions within the equipment

Table 11.4. Numbers of *Salmonella* and *Campylobacter* (log MPN per Carcass) on Chicken Carcasses Processed at Different Scalding Temperatures. Adapted from Slavic et al. (1995).

Bacteria	Scald Temperature (˚C)	Trial		
		1	2	3
Salmonella	52	3.00	3.17	3.09
	56	3.16	3.17	3.34
	60	3.50	3.48	3.36
Campylobacter	52	3.64	3.30	4.18
	56	3.39	2.94	3.93
	60	4.08	3.59	3.98

are moist and warm (birds coming out of the scalder) and favorable for microbial growth. Colonizing the defeathering equipment with a marker microorganism increased the level of cross contamination on subsequent carcasses passing by (Mead and Scott, 1994). Worn or cracked fingers can allow bacteria to penetrate below the surface, where they are more protected. *S. aureus* has been identified as one of the bacteria that best flourish under these conditions (Mead, 2000). This is of interest, because this bacteria is not noted for its ability to compete with other microorganisms. Nevertheless, it has been shown to persist in defeathering equipment for months because routine cleaning was not effective in its removal. Several researchers have demonstrated the beneficial effect of a water spray during the defeathering operation. A chlorinated spray was found to be effective, but plain water spray has also been demonstrated to be beneficial in reducing or preventing bacteria from colonizing the equipment. It should be mentioned that caution must be exerted when a water spray is used during the operation, because an aerosol can contain and transmit bacteria to other locations within the plant. Several devices, such as angled covers, have been proposed for minimizing aerosol formation and distribution. In any case, care should be given to this stage, and it is recommended that this section of the operation be well contained.

Clouser et al. (1995) have observed a significant *Salmonella* cross contamination during a conventional defeathering turkey operation (58°C scalding for 1.3 minutes, followed by a series of four pickers). When they studied another plant using a steam-spray scalding and defeathering operation, they found no significant increase in *Salmonella* level (comparing before and after defeathering). Turkeys with a high initial bacterial load ($>10^4$ cfu) showed a reduction throughout the process. Carcasses with lower counts ($<10^4$ cfu) appeared cleaner but did not show lower total counts at the end of the process.

Feather removal is more difficult in the case of ducks. The birds are scalded at 60°C, machine plucked, and then immersed in molten wax at 90°C, which is hardened by subsequent immersion in cold water. The wax is stripped from the birds by hand or machine, thus removing the fine feathers. The wax is then melted and reused. The high-temperature treatment appears to have a beneficial effect on the microbial quality of the final product, and water-chilled ducks treated with wax usually carry very low numbers of coliform bacteria (Mead, 2000). For all types of poultry, it is advisable to use a spray washer (see discussion below) after the plucking process is complete.

Evisceration

This can consist of several stages such as crop removal, opening the body cavity and removing the intestines. In small plants, the operation may be carried out manually, while, in high-volume plants, the entire process is automated, where equipment designed to perform a single task is used to perform labor-intensive, repetitive motions in an efficient and fast manner. In both manual and automated operations, there are opportunities for carcass contamination. The causes and extent may range from care taken by employees (manual operation), adjustment of equipment, automated operation and condition of the birds (e.g., time of feed withdrawal or fullness of the gut, disease conditions, such as diarrhea). Some of the modern processing lines handle over 6,000 birds per hour and, obviously, the whole evisceration process is performed quickly; but, this high-speed process can also cause some problems. Overall, it is recommended to invest in equipment designed to minimize cross contamination (e.g., apply vacuum to the cloaca while automatically pulling it out). Where possible, the equipment should be rinsed/washed on a continuous basis using a cleaning-in-place (CIP) system. This can minimize potential bird-to-bird cross-contamination problems. The main opening process usually includes two steps: cutting out the cloaca (without separating the large intestine attached to it) using a cylindrical rotary blade, followed by opening the abdominal cavity. Care should be given to prevent rupturing the intestine and spilling the gut content, because 1 ml of the gut content "fluid" can contain up to 10^9 cfu, meaning that a small volume can result in high contamination levels. It should be mentioned that equipment adjustment is required to respond to size variation among flocks. The equipment must be monitored and adjusted on a continuous basis; otherwise, incidences of intestine breakage will increase. After performing the opening cuts, an automated eviscerator is commonly used to scoop out the intestines and either leave them attached to the carcass or separate them from the carcass and hang them on a separate line (see Chapter 4). The latter system was introduced a few years ago, and it has been claimed to improve microbial quality by reducing cross-contamination problems, because the intestines are no longer attached to the carcass. The system received approval in Europe and North America in the mid 1990s after it was demonstrated that it performs at least as well as the traditional system (i.e., viscera attached to the carcass while presented to the inspector). Another improvement in reducing cross-contamination problems has been the introduction of automated carcass transfer operations (e.g., from the defeathering line to the evisceration line, and later to the chilling line). Manual transferring and/or dumping stations are more prone to accumulate microorganisms throughout the day and can increase cross contamination.

Rinsing (and Microbial Attachment)

Rinsing is an optional step that is commonly done with low- or high-pressure nozzles after the evisceration process. This step is designed to remove any visible blood spots or feces remaining on the carcass after evisceration. In addition, it helps to remove some of the nonvisible bacteria attached to the skin or other tissues. Over the past few years, different antimicrobial rinses have been suggested as demand for higher microbial standards has emerged.

Another compound, chlorine, has been used for years in countries permitting its application in spray water at a concentration of 20–50 ppm (Mead, 2000). Various pieces of equipment have been designed to perform outside and/or inside wash of poultry carcasses. Some of the old washers only consisted of a set of shower heads. However, some of the new mechanical washers are designed to wash the bird from the top down, and they include spray nozzles that are lowered into the body cavity and spray in a way that ensures the best cleaning (see Chapter 4). Removal of microorganisms is not complete because of bacterial attachment to the skin. However, removal is best achieved right after contamination and before stronger attachment occurs.

Different antimicrobial agents, including chlorine, acids, phosphates, etc., have been studied over the years with greater interest being shown over the past decade. The effect of three groups of antimicrobial agents applied at different pressures (40–90 psi) to fecally contaminated turkey carcasses, using a laboratory-type inside-outside bird washer, are shown in Figure 11.15. The results indicate that 4.25% lactic acid was best in reducing the total microbial load and coliforms (results for the latter are not presented in the figure). Tripolyphosphate and chlorine did not have a significant effect (Figure 11.15) and were similar to a water spray rinse. Mead and Scott (1994) have also reported that using a post-evisceration spray of 20 ppm chlorine for birds inoculated with a "marker" strain of *E. coli* (during the defeathering process) did not reduce the proportion of carcasses that acquired the "marker" or the number of organisms transferred. However, they mentioned that while chlorine had little direct effect on carcass contamination, it controls the buildup of bacteria on equipment and destroys any spoilage bacteria that may be present in the water supply.

The lactic acid rinse, mentioned in Figure 11.15, was also reported to be effective in reducing *Salmonella* when levels of ≥4.25% were used. Similar results were reported by Tamblyn and Conner (1997) who studied the bactericidal effects of acetic, citric, lactic, malic, mandelic, propionic and tataric acids at 0.5, 1, 2, 4 and 6% on *S. typhimurium* loosely or firmly attached to broiler skin. They compared three application methods and showed that the greatest reduction was achieved by lactic acid at their "scalding application" (2 minutes at 50°C), followed by "chiller application" (60 minutes at 0°C) and post-process dip (15 seconds at 23°C). However, it should be realized that the cost of using a ≥4% acid in a scalding tank or a chiller might be prohibited, and serious organoleptic problems may be faced. Bautista et al. (1997) reported some discoloration problems (slight bleaching when 4.25% lactic acid was used during a 10 second rinse). However, this discoloration was not a problem after water chilling the carcasses.

Water/Air Chilling

Water and air chilling are used to quickly reduce the carcass temperature, from about 40°C to a temperature below 10°C. This is one of the most

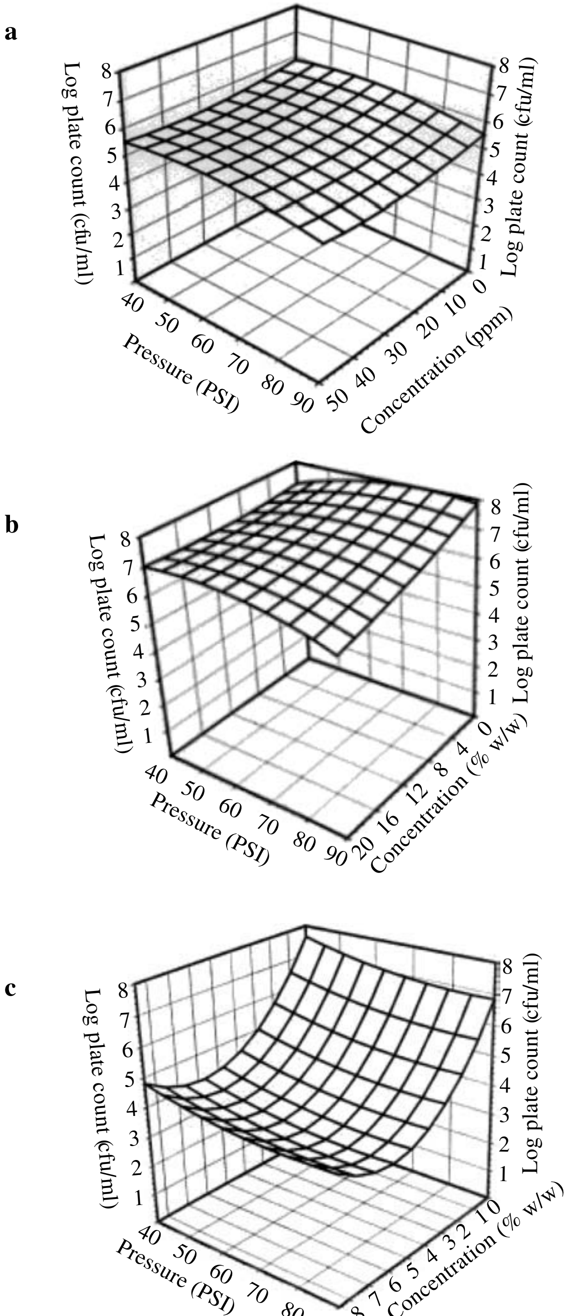


Figure 11.15. *Response Surface Diagrams Showing the Effect of Spray Wash Using (a) Chlorine, (b) Tripolyphosphate and (c) Lactic Acid on Microbial Counts on Turkey Carcasses Inoculated with Intestinal Contents. From Bautista et al., (1997). With Permission.*

important steps in suppressing microbial proliferation on the warm carcass. The two most important chilling methods are water immersion and air chilling. Both are effective, and selecting one over the other depends on factors such as water availability, price of water, electricity, the way the product will be marketed (e.g., frozen, chilled) and overall market demands. Fresh poultry can be either air chilled or water chilled, whereas frozen poultry is water chilled in certain countries (note that water pickup by water-chilled birds is higher than that by air-chilled birds as discussed in Chapter 4). As indicated in the scalding section, it is recommended that air-chilled birds be scalded at a low temperature to prevent the epidermis from coming off the skin during the plucking operation. Air chilling, which is very common in Europe and currently becoming popular in Canada, can include a mist or water spray to facilitate chilling and to prevent drying during the operation (≥1 hour). Some of the large capacity air-chilling operations have looping lines that can extend for several kilometers within the refrigeration tunnel. Data comparing water- and air-chilling units are shown in Table 11.5. Total microbial counts on carcasses were lower after water chilling and equal to or higher after air chilling. Levels of *Pseudomonas* spp. were relatively high after chilling, in all processes of broilers and turkeys (Mead et al., 1993).

Past evaluations of continuous immersion chillers have shown that the number of microorganisms in the water depends, among other things, on the water overflow expressed as the amount of water used per 1 kg of carcass mass. Using an overflow of about 2:l resulted in a skin microbial count reduction of 60–98% (Bailey et al., 1987). This indicates that a water-chilling system can be operated in a manner that reduces total microbial counts.

Table 11.5. Effect of Processing Plant (Five Different Chicken Plants; Except #2—Turkeys) and Water-Chilling Method on *Pseudomonas* spp. Contamination of Neck Skin. Adapted from Mead et al. (1993).

Plant	#1		#2		#3		#4		#5	
Chilling Method	Water		Air		Water		Air		Air	
After										
Bleeding	2.3[a]	(8)[b]	2.5	(8)	<2.0	(4)	<2.0	(8)	<2.0	(5)
Scalding	<2.0	(3)	<2.4	(6)	<2.0	(1)	<2.0	(1)	<2.0	(0)
Defeathering	2.3	(13)	3.2	(15)	<2.0	(1)	2.3	(8)	<2.0	(3)
Evisceration	3.0	(15)	3.4	(15)	2.4	(11)	<2.1	(6)	<2.1	(6)
Washing	2.7	(12)	2.7	(15)	2.2	(13)	<2.1	(7)	<2.2	(7)
Chilling	3.3	(15)	3.9	(15)	<2.0	(2)	2.6	(9)	3.2	(15)
Packaging	3.9	(15)	4.0	(15)	NA	NA	2.9	(13)	3.5	(15)

[a] Mean ($\log_{10}$) per g of neck skin.

[b] Number of positive samples out of 15 by direct plating.

NA, not available.

However, some criticism has been pointing to the fact that certain pathogens, which may be present in a low number of birds prior to chilling, may be distributed to many other carcasses. Some studies have shown no increase in *Salmonella* as a result of immersion chilling, while others have found higher incidences. Busta et al. (1973) studied three turkey processing plants and found *C. perfringens* in 53%, *S. aureus* in 22%, *Salmonella* in 17.6% and coliforms in 100% of chilled water samples. In one particular plant, the incidence of these organisms on turkey skins did not differ much before and after chilling: *C. perfringens* 87% before, 83% after; *S. aureus* 71% before, 67% after; *Salmonella* 28% before, 24% after; and coliforms 100% before and after.

In adequately controlled chilling systems, there is usually a net reduction in bacteria count due to the washing effect. Blank and Powell (1995) indicated that aerobic plate count and coliform count may be reduced by 50 and 90%, respectively. The results are in agreement with James et al. (1992; see Figure 11.14). Figure 11.16 shows the microbial results during the day which reached a plateau after about 2–3 hours (similar to what is observed in a scalding tank). The count of microbial populations on chilled carcasses obtained after 3 hours was similar to that obtained at the end of the shift after 8 hours. The addition of chemicals to an immersion water chiller can help control the microbial population. Different forms of chlorine are commonly used and, depending on legal limits in various countries, can reach a level of 20 ppm. Such a level can help control microorganisms, but it should be remem-

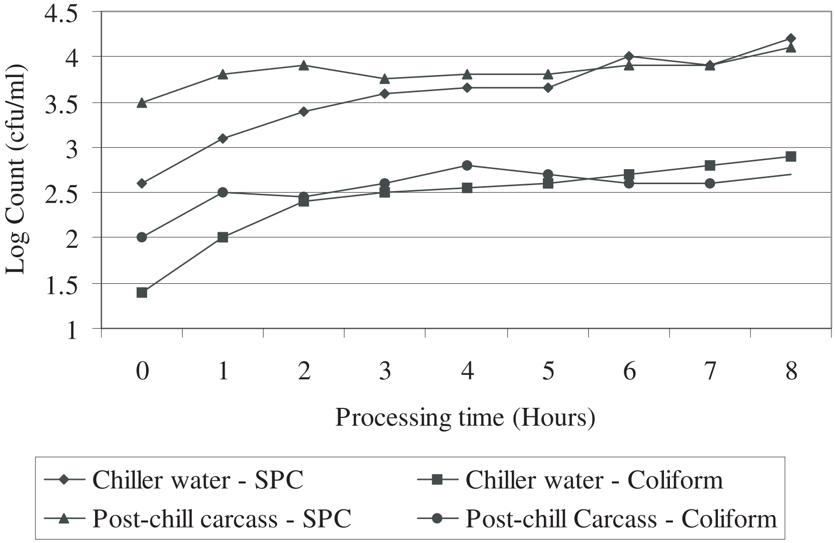


Figure 11.16. *Standard Plate Count (SPC) and Coliform Populations (Log cfu/mL) as a Function of Time of Day in Chiller Water and on Post-Chilled Carcasses. For Each Point,* n = *5. Adapted from Blank and Powell (1995).*

bered that a total eradication of *Salmonella* occurs at a chlorine concentration of 300–400 ppm. Such a high level is not feasible because it would cause massive bleaching of the skin and, in addition, the birds would have a strong chlorine odor for an extended period of time. The chlorine level in the chiller should be monitored on a continuous basis because chlorine can react with organic material, and its effective concentration be reduced. The use of 5 ppm free chlorine (measured at the overflow from the chiller) was reported as beneficial in reducing the microbial load on commercially processed broilers (Waldroup et al., 1992). The authors have also examined other modifications (carcass wash, countercurrent scalding) suggested by the U.S. National Broiler Council and approved by the Food Safety and Inspection Service. All modifications assisted in achieving the final goal of reduced microbial counts on processed broilers. Adding hydrogen peroxide at a level sufficient to reduce 95% of the total bacterial counts also requires high levels, in excess of 6,000 ppm. Such levels are not feasible and can cause bleaching and blotting problems. The use of various acids can assist in reducing *Enterobacteriaceae* and other bacteria (Tamblyn and Conner, 1997). This is similar to the notion previously discussed in the rinsing section. But, it seems that rinsing allows the use of a higher concentration of acids/chlorine/phosphate in a more economical way, because the short contact time does not result in major bleaching problems. In any case, a certain level of chemical control (e.g., chlorine) helps in keeping the chill water clean.

Allen et al. (2000) have evaluated six chilling systems in normal commercial use. This provided an interesting comparison of the operation and microbial quality of the birds. The main features of these systems, designated A–F, are summarized in Table 11.6. The water chiller (A) was a conventional, counterflow, three-stage unit that was operating in accordance with the U.K. Poultry Meat Hygiene Regulations with respect to water usage. The water was chlorinated to give a mean total residual of 45 mg/L, with 20 mg/L in the final unit. The temperature of the water ranged from 15.9°C at the carcass entry point to 5.1°C at the chiller exit. The residence time for carcasses was about 40 minutes. The residence time in the air chillers varied according to carcass size, staff break times, line stoppages and whether or not carcasses were stored in the chiller overnight. The air chillers ran at a nominal 3°C. Chiller C was a "clipbar" type in which carcasses were hung in horizontal rows that moved in sequence through a chilling tunnel, with a residence time that was generally <90 minutes. In the four "Ventstream" chillers, carcasses moved through a chill room on a continuous-looped shackle line (residence time was also generally <90 minutes). Water sprays were used in a partly separated prechill area in two of the air-chilling systems (D and E) and in the first section of the clipbar tunnel (C). In the spiral Ventstream chiller (B), the carcasses passed through two spray cabinets where low volumes of water were applied. Chlorinated water (50 mg/L) was used in the sprays in chillers

Table 11.6. Description of Investigated Chillers From Allen et al., (2000). With Permission.

	Chilling System Code					
	A	B	C	D	E	F
Chill method	Water	Air	Air	Air	Air	Air
Chiller type	Spin	Spiral Ventstream	Clipbar	Spiral Ventstream	Spiral Ventstream	Spiral Ventstream
Separate pre-chiller	NO	NO	NO	YES	YES	NO
Nominal pre-chill	NA[a]	NA	NA	10	10	NA
Water spray	NA	YES	YES	YES	YES	NO
Spray cabinet	NA	YES	NO	NO	NO	NA
Chlorination of water	YES	YES	YES	YES	NO	NA
Intensity of spray	NA	Light	Moderate	Moderate	Heavy	NA

[a] Not applicable.

B, C and D. The authors mentioned that although air chilling has become increasingly popular in the United Kingdom, reflecting the growth in demand for fresh poultry, it is often modified to incorporate fine water sprays in the first stage. This modified process, known as "evaporative chilling," utilizes the extra cooling effect that occurs as water evaporates from the carcass surface, and it also minimizes weight loss.

The results (Figure 11.17) obtained for water immersion chilling confirmed previous experience that the washing effect reduces microbial contamination of carcasses, although initially the numbers of pseudomonades tended to increase. The commercial air chillers varied in design and mode of operation, but had little overall effect on microbial contamination of the skin. When a completely dry process was used, microbial numbers were reduced approximately tenfold in the body cavity. However, the use of water sprays tended to increase contamination of the cavity, while relatively heavy spraying using nonchlorinated water resulted in a substantial increase in the numbers of pseudomonades.

Cutting, Storage and Distribution

Fresh poultry is commonly sold as whole carcass, cut-up parts or minced meat (see Chapter 6, for parts selection and definitions). The meat can be packaged either in individual bags, trays wrapped in polyethylene or in bulk without individual wrapping.

The storage life of fresh poultry greatly depends on temperature and the initial microbial populations (number and type) as shown in Figure 11.8. An

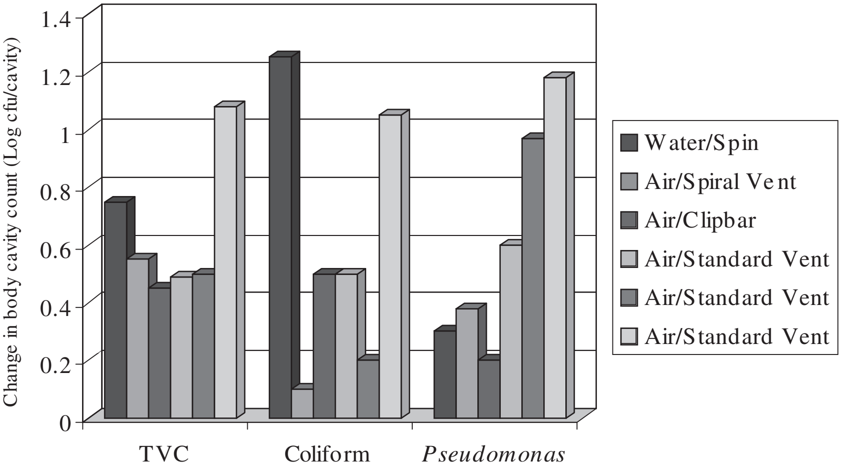


Figure 11.17. *Microbial Quality of Chicken Carcasses Chilled by Air or Water (See Also Table 11.6); TVC = Total Viable Count. Adapted from Allen et al. (2000).*

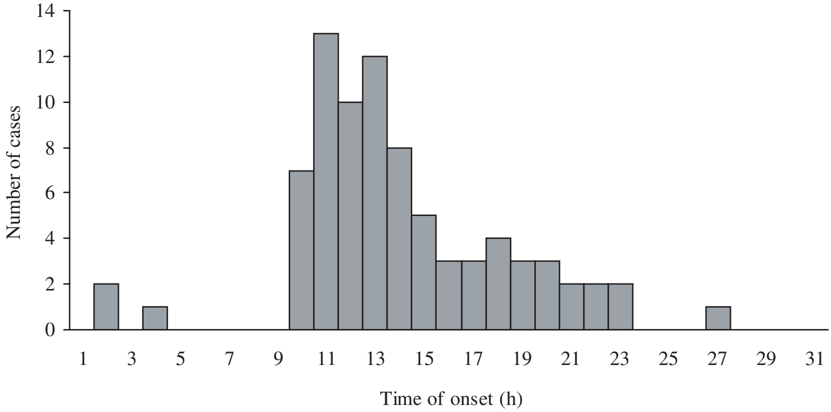


Figure 11.18. *Typical Epidemic Curve for the Onset of* Clostridium perfringens *Gastroenteritis Symptoms. From Center for Disease Control, Athens, GA.*

early observation indicated that the average shelf life of fresh, eviscerated and cut-up poultry stored at 0°C is about 15–18 days, at 4.4°C it is 6–8 days, and at 10.6°C it is 2-3 days (Ayres et al., 1950). Later studies indicated similar trends where meat stored at 10°C will spoil about twice as fast at 5°C and three times as fast at 15°C (Cox et al., 1998). Other factors related to sanitary processing conditions, such as scalding temperature and chill water chlorination, affect the initial microbial load and, therefore, the shelf life of the meat. The type of spoilage flora developing on eviscerated chicken is influenced by storage temperature (Table 11.7). It is interesting to note that initially, the predominant species found on broiler carcasses are mesophylic such as micrococci, Gram-positive rods and flavobacterian. If the meat is held at 1°C, psychrotroph strains of *Pseudomonas* will eventually dominate the culture and cause spoilage. It should be mentioned that since Barnes and Thornley (1966) have found *P. putrefaciens* as the principle spoilage bacteria on fresh poultry, the species has been reclassified as *Alteromonas putrefaciens*. This bacterium is present at relatively low numbers on carcasses immediately after processing. On the live bird, it is found on the feathers and feet. Later, during processing, it can be isolated from chill tank water, but it is rarely found in the intestines. If the meat is held at 10°C, *Pseudomonas, Acinetobacter* and *Enterobacteriaceae* spp. multiply fairly rapidly. At 15°C, *Acinetobacter* and *Enterobacteriaceae* spp. dominate the microbiota because their optimum growth temperatures are higher than those of the *Pseudomonas*.

Although spoilage bacteria grow at refrigerated temperatures, their multiplication rate is slower at a lower temperature. Most mesophylic bacteria will survive but will not multiply at refrigerated temperatures. The generation time of a mesophylic bacteria such as *E. coli* has been reported to be 0, 0, 20, 6, 2.8, 1.3 and 0.5 hours at temperatures of −2, 1, 5, 10, 15, 20, 25 and 30°C, respectively. (Note: the generation time at 0°C might exceed 100 hours).

Table 11.7. Spoilage Microflora of Eviscerated Chickens Initially, and After Storage at 1, 10 and 15˚C Until Spoiled. From Barnes and Thornley (1966). With Permission.

	Number of Strains			
	Initial	1˚C	10˚C	15˚C
Total strains	58	40	80	69
Gram-positive rods	14	0	4	6
Enterobacteriaceae (lactose positive)	8	0	3	10
Enterobacteriaceae (lactose negative)	0	3	12	17
Micrococci	50	0	4	0
Streptococci	0	0	6	8
Flavobacteria	14	0	0	0
Aeromonas	0	0	4	6
Acinetobacter	7	7	26	34
Pigmented *Pseudomonas*	2	51	21	9
Non-pigmented *Pseudomonas*	0	20	12	2
Pseudomonas putrefaciens	0	19	4	4
Unidentified	5	0	4	4

When spoilage microorganisms start to grow on poultry meat, they produce by-products such as slime (a protective carbohydrate secretion for the bacteria), off-odors, etc. The number of bacteria required to cause a notable change is about 10^6 to 10^8 cfu/cm^2. At the beginning, a small psychrotroph population would mainly utilize glucose or other simple sugars as an energy source. The by-products of glucose do not contribute substantially to detectable spoilage. However, as glucose is depleted, the bacteria switch to other compounds, such as amino acids, that cause the formation of odorous by-products (Pooni and Mead, 1984). Various spoilage signs have been reported, usually starting with the appearance of small, translucent dots (i.e., microbial colonies) on the cut surfaces of skin/meat. Initially, the colonies appear as tiny water droplets, but later they grow, become opaque and finally create a uniform, sticky or slimy layer. At one of these stages, the meat can develop an offensive ammonia odor or a “dirty dishrag” odor. Colored colonies (e.g., gray, yellow, brown) are usually associated with a specific type of spoilage microorganism present on the meat. It should be pointed out that in order to obtain meaningful counts of the bacteria present on the meat, an appropriate incubation temperature should be used (i.e., usually 5°C is used to prevent the growth of mesophylic bacteria and encourage psychrotroph growth). It is generally recommended that the agar plates be incubated at or near the temperature at which the product is stored. Enumeration of mesophylic bacteria can be more difficult than that of psychrotrophs, because some psychrotrophs can grow at elevated temperatures. For example, *Pseudomonas* and *Aerobacter* are capable of normal development at 0 to 30°C; however, at 35°C, *Pseudomonas* will not grow and *Aerobacter* will be inhibited. Knowing the maximum growth temperature of various psychrotrophs is important in determining the incubation temperature needed to enumerate mesophylic bacteria in a mixed population.

Overall, bacteria isolated from temperature-abused fresh poultry meat are different from those isolated from meat held at an appropriate storage temperature (<5°C). Pooni and Mead (1984) indicated that at 20–22°C, 70% of the bacteria were *Proteus* species (mesophylic) and only 20% of the bacteria were *Pseudomonas* (psychrotrophs). Others have also shown a smaller proportion of *Pseudomonas* on temperature-abused poultry meat.

Frozen Storage

Freezing is used to extend the shelf life of food products for many weeks or months. During frozen storage, water is not available to the microorganisms, and most cannot grow. Poultry meat freezes at a temperature of −1 to −2°C because of its salt and mineral contents that suppresses the freezing point. During freezing, a portion of the microbial population will be killed or sublethally injured. Survival of bacteria after thawing can range from 1–100%, but commonly it is about 50% depending on factors such as the food composition (e.g., high-, low-fat content) and freezing rate. It is known that slow freezing results in greater destruction of microorganisms than freezing at a fast rate. The reason for this is that during slow freezing, an intra- and extracellular osmotic gradient forms throughout the cell and causes damage to the cell structure. During very fast freezing, no such gradient is formed. When the goal is to preserve a bacteria culture, a very rapid freezing (liquid nitrogen at around −190°C; see additional discussion in Chapter 7) is the preferred way to minimize damage to the microorganisms. The effect of freezing on the shelf life of thawed chicken meat has been studied by various researchers, and most reports indicate no major differences in shelf life after the meat has been thawed (Sauter, 1987).

SIGNIFICANT MICROORGANISMS IN POULTRY MEAT

Poultry meat, as well as other red meats, can be a vehicle for transferring foodborne diseases, especially *Salmonella* and *Campylobacter,* to humans. Illnesses from each of these agents have an estimated annual incidence in the United States alone of up to 4 million cases (Bryan and Doyle, 1995). The organisms can be carried asymptomatically in the intestine of a varying proportion of healthy animals and later contaminate processed carcasses. The prevalence of some potential pathogens in poultry is presented in Table 11.8,

Table 11.8. Prevalence of Potential Pathogenic Bacteria in Raw Chicken. Summary of Studies Compiled by Mulder and Schlundt (1999).

Bacteria	Prevalence (%)
Campylobacter jejuni	0–100
Clostridium perfringens	63
Clostridium botulinum	0.3
Escherichia coli O157:H7	1.5
Salmonella spp.	0–100
Staphylococcus aureus	7–88
Listeria monocytogenes	5–60
Yersinia enterocolitica	8

which provides a summary of numerous studies conducted in different countries over the past few decades. Mead (2000) has also summarized reports on *Salmonella* contamination on fresh poultry meat marketed in Germany, India, the Netherlands, the United Kingdom and the United States between 1990–1994 and indicated levels varying from 4–100%. Other foodborne pathogens that can be present on poultry carcasses include *Clostridium perfringens,* a common intestinal organism, and *Staphylococcus aureus,* which is carried on the skin and in the nasopharynx of some birds and may also be acquired from colonization of processing equipment. Generally speaking, both organisms occur in low numbers, and meat is unlikely to become hazardous unless it is temperature abused or these bacteria are allowed to extensively multiplicate (Mead, 2000).

Foodborne diseases are caused by microorganisms that either invade the body of the host or secrete toxins to the food prior to its consumption. Invading microorganisms can cause gastrointestinal disturbances or septicemia (invasion into the bloodstream). It should be remembered that gastrointestinal disturbances, following ingestion of food, can also result from overeating, allergies, chemical poisoning or toxic plant/animal material.

Microorganisms responsible for foodborne diseases can be divided into those that cause a food infection resulting from ingestion of pathogens that invade and grow inside the human body (e.g., *Salmonella*) and food poisoning causing illness by ingestion of toxins. Toxins produced by noninvading microorganisms can be divided into exotoxins, which are secreted into the environment/food by bacteria such as *C. botulinum,* and endotoxins, which are released upon the death of an organism (e.g., lipopolysaccharide components of Gram-positive cell walls released upon lysis).

The following discussion will describe the main foodborne diseases associated with poultry meat.

Salmonella

Salmonellosis is a food infection that can result from ingestion of any one of the 2,500 *Salmonella* serovars. It should be mentioned that in the past, microbiologists and epidemiologists treated all the serovars as though each was a species; however, some significant changes in toxonomy have placed all *Salmonella* into two species: *S. enterica* and *S. bongori,* which are divided into six subspecies or groups—most of which are classified under *S. enterica* (Jay, 2000). The food infection, caused by some of the serovars but not all, is the result of endotoxins within cells ingested by the host. The common symptoms consist of vomiting, diarrhea (i.e., two defense mechanisms of the body to remove an infectious material from the body as fast as possible) and irritation of the intestine (Table 11.9). It is estimated that approximately 10^6 organisms must be ingested for infection to occur in an adult. Mortality from salmonellosis is generally low, with fatalities occurring in infants, aged or people who are already affected by other diseases. The microorganism is a facultative Gram-negative rod. It is frequently found in the intestinal tracts of animals (e.g., beef, hogs, poultry) and humans without producing apparent symptoms of infection. Although *Salmonella* can be present in the poultry digestive tract (carrier without showing symptoms), a major cause of transfer to the meat results from cross contamination of carcasses during the primary process operation (slaughter, scalding, evisceration and chilling). Later, cross contamination of raw and cooked food products is a potential problem when one touches a surface previously in contact with raw meat or its juices (e.g., cutting boards, knives, unwashed hands). A risk also exists when meat is undercooked (i.e., where a temperature of >65°C has not been reached). Cooking procedures normally used for poultry meat are sufficient to destroy most serovars of *Salmonella*. Overall, *Salmonella* is a heat-sensitive bacteria that usually takes 5 minutes to destroy at 62.2°C. At lower temperatures such as 60°C, it takes 12 minutes, and at 57.2°C it takes 37 minutes. Most cooking guidelines for poultry meat specify a minimum internal temperature of 70°C, which results in fast inactivation of the bacteria. Other preventive measures, such as competitive exclusion during the growing period and carcass decontamination with chlorine/acid washes, have been discussed earlier in this chapter.

Overall, domestic poultry may acquire *Salmonella* from three main sources. The first is via parents/breeding stocks; the second is from the environment (contact with wild birds, mice); and the third is due to consuming contaminated feed. Eggs can be contaminated with this organism, either internally or externally, by the time they are laid. Most *Salmonella* servovars are confined to the intestines of infected birds and are excreted in the feces. During hatching, a few contaminated eggs can spread the bacteria. Later, the farm birds that carry *Salmonella* shed the organisms. Once introduced, infection may be spread via drinking water or feed. Other potential vectors include wild birds, rodents, insects, domestic animals and humans.

Table 11.9. Characteristics of Some Common Food Poisonings and Infections. Based on Data from Jay (2000) and Marriott (1999).

Illness	Causative Agent	Symptoms	Average Time Before Onset of Symptoms	Foods Usually Involved	Preventive Measures
Salmonellosis (food infection)	Infection produced by ingestion of any of more than 2,500 species of *Salmonella* that can grow in the human gastrointestinal tract	Nausea, vomiting, diarrhea, fever, abdominal pain; may be preceded by chills and headache	6–24 hours	Insufficiently cooked or warmed-over meat, poultry, eggs and dairy products; these products are especially susceptible when kept unrefrigerated for a long time	Cleanliness and sanitation of handlers and equipment; prevent cross contamination of raw and cooked meat; pasteurization, proper refrigeration and packaging
Campylobacter (food infection)	*Campylobacter jejuni* and *Campylobacter coli*	Headache, fever, abdominal pains and diarrhea	1–7 days	Insufficiently cooked poultry and meat products, unpasteurized milk and dairy products	Cleanliness and sanitation of handlers and equipment; pasteurization and proper cooking.
Listeria (food infection)	*Listeria monocytogenes*	Fever, headache, nausea, vomiting, meningitis, miscarriage, septicemia	1–4 weeks	Raw and pasteurized milk, meat and meat products, soft cheese, raw vegetables	Cleanliness and sanitation of equipment, pasteurization and proper cooking

(continued)

Table 11.9. (continued)

Illness	Causative Agent	Symptoms	Average Time Before Onset of Symptoms	Foods Usually Involved	Preventive Measures
Botulism (food poisoning)	Toxins produced by *Clostridium botulinum*	Impaired swallowing, speaking, respiration, coordination. Dizziness and double vision	12–48 h	Canned low-acid foods including canned meat and seafood, smoked and processed fish	Proper canning, smoking and processing procedures. Cooking to destroy toxins, proper refrigeration and sanitation
Staphylococcal (food poisoning)	Enterotoxin produced by *Staphylococcus aureus*	Nausea, vomiting, abdominal cramps due to gastroenteritis (inflammation of the lining of the stomach and intestines)	3–6 h	Custard and cream-filled pastries, potato salad, dairy products, cooked ham, tongue and poultry	Pasteurization of susceptible foods, proper refrigeration and sanitation
Clostridium perfringens (food infection)	Toxin produced by *Clostridium perfringens*	Nausea, occasional vomiting, diarrhea, and abdominal pain and flatulence	8–24 h	Cooked meat, poultry and fish held at nonrefrigerated temperatures for long periods of time	Prompt refrigeration of unconsumed cooked meat, poultry or fish; maintain proper refrigeration and sanitation
Escherichia coli		See Table 11.10			

Campylobacter

Campylobacter jejuni and *Campylobacter coli* are Gram-negative, spiral-curved, rod-shaped bacteria that cause food infection when ingested. The infection dose is fairly low—as few as 500 bacteria can cause an illness. The symptoms of infection include diarrhea, fever, severe abdominal pain, headache, bloody stools, nausea and sometimes vomiting (Table 11.9). The microorganism is aerophilic and does not usually multiply at temperatures <30°C. It is found in the intestinal tract of warm-blooded animals such as poultry and beef and also in contaminated water and sewage. As with *Salmonella,* cross contamination of carcasses during processing and handling is a problem. Overall, the bacteria can be controlled by cooking because it is a heat-sensitive bacteria, and normal cooking temperature is sufficient for its destruction. Mead (2000) indicated that the majority of cases are sporadic, with outbreaks being relatively uncommon. Of all the reported outbreaks of foodborne disease in Europe during 1990 and 1991, only 1.1% were due to *Campylobacter*. Data from sporadic cases suggest that handling, preparation of poultry and the consumption of undercooked chicken are particular risk factors. In the United States, the consumption of chicken, Cornish game hen and, to a lesser extent, turkey meat has been linked to human campylobacteriosis. In most countries, poultry meat is frequently contaminated with *Campylobacter,* and levels of 0–100% may occur (Table 11.8). Counts from skin can exceed 10^4 per g, but levels of contamination are often reduced during processing to about 10 per g or 10^3 to 10^6 per carcass. The organisms can be isolated from breasts, wings, thighs and abdominal cavities, indicating general distribution over the carcass. Some reports show a lower contamination rate for frozen poultry in comparison with chilled carcasses, but this may be influenced by the method of isolation and whether or not damaged cells were recovered. Studies suggest that *Campylobacter* may survive on frozen chicken for at least 3 to 4 months.

Listeria monocytogenes

Listeria monocytogenes is a Gram-positive, nonspore-forming, catalase-positive rod. It produces lactic acid from glucose and other fermentable sugars and usually tends to be associated with *Lactobacillus* in nature. Six species of *Listeria* are recognized by the possession of antigens that give rise to 17 servovars. The primary pathogenic species, *L. monocytogenes,* is represented by 13 servovars. The nutritional requirements are typical of other Gram-positive bacteria, and they can grow in many common laboratory media. Although they grow best at pH 6–8, some strains, including *L. monocytogenes,* can grow over a pH range of 4.1–9.6 (Jay, 2000). The mean minimum growth temperature is 1°C, meaning that it can grow in refrigerated meat. The symptoms associated with this food infection are listed in Table 11.9. Overall, *Listeria* is widely distributed in the environment and can be found in animal feces and decaying organic material in soils, water and sewage. It is well established that any fresh food product of animal or plant origin may contain varying numbers of *L. monocytogenes*. It is a common contaminant of raw poultry, and about 60% of chicken carcasses may carry the organism in low numbers (Table 11.8; Mead, 2000). The bacteria is heat sensitive and destroyed by normal cooking procedures. It has been shown that a milk pasteurization protocol of 62.8°C for 30 minutes or 72°C for 15 seconds is adequate to reduce normally existing numbers to below detectable levels. Cooked chicken nuggets and cook-chill poultry have been implicated in sporadic cases of foodborne listeriosis, which resulted from cross contamination. In the United States, turkey hot dogs were recently involved in a large outbreak where *L. monocytogenes* was isolated and identified (by DNA typing) from patients and hot dogs kept in the patients' refrigerators. The latter part is mentioned because identifying a causative agent is not always so simple, especially when symptoms start to show a few weeks after the original infection. This case involved a massive product recall and a major plant renovation.

Clostridium botulinum

Food poisoning can result from ingestion of a toxin produced by this Gram-positive, rod-shaped bacteria. The bacteria forms spores that make it very resistant to conventional heat treatments (boiling at 100°C). It is found primarily in soil and debris stuck to feathers and skin. The toxin is extremely potent, and nanogram quantities are extremely dangerous. The botulism toxin is actually one of the most potent toxins known to human beings. It affects the central nervous system, actually blocking the chemical messenger (acetylcholine; see Chapter 3) used to transfer messages among nerve fibers and, by doing so, effectively blocking messages from the brain. Some of the initial symptoms include impaired vision, speaking and breathing (Table 11.9), all of which are directly affected by interrupting the communication between the brain and the peripheral nerves. Failure of the respiratory system represents the most immediate danger to the victim, and therefore, one of the most important initial treatments is assistance in breathing (often, victims are placed in a pressure chamber used to treat diving accidents). The toxin is actually activated by the host's digestive system (i.e., trypsin enzyme) prior to being absorbed into the bloodstream. Historically, improperly home-canned fruits, vegetables and meat, with low to medium acidity, constituted the largest potential source of botulism. Because the bacteria is anaerobic, canned and vacuum-packaged foods, including meat, are potential sites for growth. Overall, the distribution of botulinum spores in meat is very low, and poisoning from canned or vacuum-packaged meats is rare. The meat industry uses nitrite (a chemical means) to inactivate the spores. This is an effective way of inactivating the spores in meat products that are not canned (i.e., not cooked at high pressure above 100°C). The toxin itself is relatively heat liable (inactivated at 85°C for 15 minutes, or 100°C for 1 minute), while the spores are resistant to heat (destroyed at 120°C for 4 minutes). Other factors that can be used to suppress growth are water activity (<0.94), pH (<4.65), salt ($>10\%$) and refrigerated temperature. Usually, most *C. botulinum* species will not grow at <7°C. That is one of the reasons cooked meat products should be refrigerated at all times. In the case of canned food, cans showing swelling (due to gas produced by microorganism activity) should always be discarded.

Clostridium perfringens

Clostridium perfringens is a Gram-positive rod that grows under anaerobic conditions and can cause food infection in humans. This spore-forming microorganism is widely spread and can be found in soil, water and the intestinal tracts of animals and humans. The microorganism can produce a variety of toxins and abundant amounts of gas when growing under mesophylic conditions. A large number of organisms must be ingested ($>10^8$ cells) by the host for this type of food poisoning to occur. Symptoms are relatively mild and include diarrhea, abdominal pain and nausea (Table 11.9). Reducing the risk of food infection resulting from this microorganism includes rapid chilling of cooked meat and other food products. Proper refrigeration of food at all times, especially leftovers, and good sanitation are essential. One of the main reasons for this microorganism's success is the fact that during cooking, a substantial number of the non-spore-forming microorganisms are destroyed. Later, during slow cooling, *C. perfringens* spores present in the food can germinate without facing a lot of competition from other microorganisms. When foods are held on steam tables, temperatures should be kept above 60°C. In addition, when leftover foods are reheated, thorough heating is required to destroy the organism and its toxins. Figure 11.18 shows a typical epidemic curve for onset of *Clostridium perfringens* gastroenteritis symptoms, indicating the times people got sick after eating the food. As can be seen, the average time was 11–13 hours; however, a fairly large variation in time for onset was seen. This can be important when a patient is interviewed by a physician trying to find out the time the food was consumed. Overall, variation among people, age differences and the quantity of the infectious dose consumed can result in differences in the onset time.

Staphylococcus aureus

Staphylococcus aureus can cause food poisoning by ingesting the enterotoxins produced by this Gram-positive, facultative anaerobic cocci. The enterotoxins cause inflammation of the stomach and the intestinal lining, called gastroenteritis. Usually, high levels of the microorganism (10^5–10^6 cells/g) must be present and, as with other food poisoning, the state of the individual (age, health, other illnesses) affects the response. Symptoms include abdominal cramps, vomiting, possible diarrhea and nausea (Table 11.9). The toxins affect the central nervous system, but mortality is very low. If mortality does occur, it is usually due to added distress in people already suffering from other illnesses. The organism is widely spread in nature and can be isolated from many healthy individuals. Thus, handling of food by infected people is probably one of the greatest sources of staphylococci food poisoning and is one of the most commonly reported foodborne diseases in North America. The microorganism is a poor competitor mesophile. Under favorable conditions, it will multiply to high numbers without significantly altering the flavor, color or smell of the food. Toxin production is most rapid at about 20°C in foods with fairly neutral pH. However, the microorganism can grow at temperatures between 7–45°C. Foods associated with staphylococci food poisoning are usually high-protein foods (dairy products, meat products, custard and cream-filled pastries) as well as foods that are handled frequently during preparation. The organism is quickly destroyed by heat (66°C for 12 minutes and <1 minute at 100°C). However, the endotoxins require a severe heat treatment (121°C for 30 minutes) to be destroyed.

Escherichia coli

Escherichia coli is a Gram-negative, facultative, rod-shaped bacteria. It is found in great numbers in the intestinal tracts of animals and humans, soil, water, fruits and vegetables. *E. coli* was established as a food pathogen in 1971 when imported cheeses, coming to the United States, were contaminated with an enteroinvasive strain that caused illness in a few hundred people. Prior to that, at least five outbreaks were reported in other countries, with the earliest being from the United Kingdom in 1947. As a human pathogen, evidence suggests that it was recognized as a source of infant diarrhea as early as 1700. Pathogenic strains of *Escherichia* are serologically typed in the same way as other *Enterobacteriaceae*. For the genus *E. coli,* 200 O (somatic antigen) serotypes have been recognized. Because the flagella proteins are less heterogeneous than carbohydrate side chains that make up the O group, considerably fewer (about 30) H antigenic types exist (Jay, 2000). There are four major types of pathogenic *E. coli* (Table 11.10) and two minor types. The presence of *E. coli* can be used as an indication for fecal contamination in drinking water. In fresh meat, the presence of high numbers can indicate poor sanitary conditions during the processing and handling of the meat.

Hepatitis A

Hepatitis A is a virus that can attack human liver cells. The virus has a single-stranded RNA genome and requires a host cell in order to replicate.

Table 11.10. Types and Symptoms of Different *E. coli* Strains.

Organism	Infectious Dose	Time to Onset	Duration	Symptoms	Other Comments
Enterotoxigenic (ETEC): toxicoinfection	10^6–10^8 cells	1–3 days	Days	Watery diarrhea, dehydration	"Traveller's Diarrhea"
Enterohemorrhagic: O157:H7 toxicoinfection	10^1–10^3 cells	3–7 days	Days to weeks	Abdominal pain, diarrhea, vomiting, nausea Bloody diarrhea, kidney failure	Case fatality rate is high "Hamburger Disease"
Enteroinvasive (EIEC): infection	10^8 cells	1–3 days	Days to weeks	Diarrhea, dehydration, fever, chills	Not a significant cause of foodborne illness in North America
Enteropathogenic (EPEC)	10^6–10^{10} cells	1–6 days	Days to weeks	Diarrhea	Not a significant cause in North America

The virus belongs to the *Picornaviridae* family. It can be transferred via food, but would obviously not multiply in food. The most common contamination source is from food handlers who are sick and shed the virus or have previously had hepatitis, recovered and are still shedding the virus. The virus can also spread via polluted water. Overall, there are more documented outbreaks of hepatitis A traced to food than any other viral infection. The infection symptoms appear one to seven weeks after consuming the food (typically four weeks). This usually makes it more difficult to trace the source. In any case, a common source of food associated with the outbreak (more than two people suffering from the same symptoms) is investigated. Also, in this case of viral infection, attention to sanitation and proper food preparation are essential in preventing the spread of the disease. New employees should be required to go through a medical examination, and regular employees should report any sickness/infection to their employer.

SANITATION IN POULTRY PROCESSING PLANTS

Maintaining a clean food processing operation, on a continuous basis, is not an easy task. The operation requires good planning, adequate equipment design, commitment of all employees (i.e., not only the sanitation crew), knowledge of available cleaning compounds and an adequate supply of clean water.

Some of the main reasons for maintaining good sanitation include the following:

- Fresh poultry meat and processed products are perishable ingredients that will quickly spoil without adequate sanitation and storage.
- The company reputation is on the line each time a consumer buys a product. Gaining brand loyalty is a very time-consuming process, while losing it can take only one major incidence of food poisoning.
- Meeting legal requirements is a mandatory requirement. Failure to do so will result in plant closure, bad publicity and severe financial losses.
- Avoiding lawsuits is becoming a major issue when consumers suffering from using/eating a defective product (e.g., microbially contaminated, presence of glass/metal) seek compensation. Legal bills, compensation awards and bad publicity can result in bankruptcy.
- Avoiding recalls, either mandatory or voluntary, can save the company bad publicity and expenses. National or international recalls can be extremely complex, expensive and difficult to conduct.
- Maintaining a competitive edge is the goal of every company. Bad publicity in cases of food poisoning, associated with a specific company can result in significant financial penalties (e.g., loss of sales, decline in stock price). In the currently competitive global economy, switching

from one brand to another is very easy for the average consumer (e.g., switching from one brand of hot dogs to another might only require moving less than 1 m along the display cooler of a big supermarket).

An important factor in minimizing microbial problems is the type of equipment used and the material used for its construction. Some of the main hygienic design principles include the following:

- All surfaces in contact with food must be inert (and not migrate to the food).
- All surfaces must be smooth for easy cleaning and for minimizing harboring bacteria.
- All surfaces must be visible for inspection, or readily disassembled, or demonstrate good cleaning ability.
- All surfaces must be readily accessible for cleaning (manual or cleaning-in-place).
- Equipment and surfaces should be capable of being self-drained/emptied (Figure 11.19).
- Equipment should protect food from external contamination (e.g., grease).

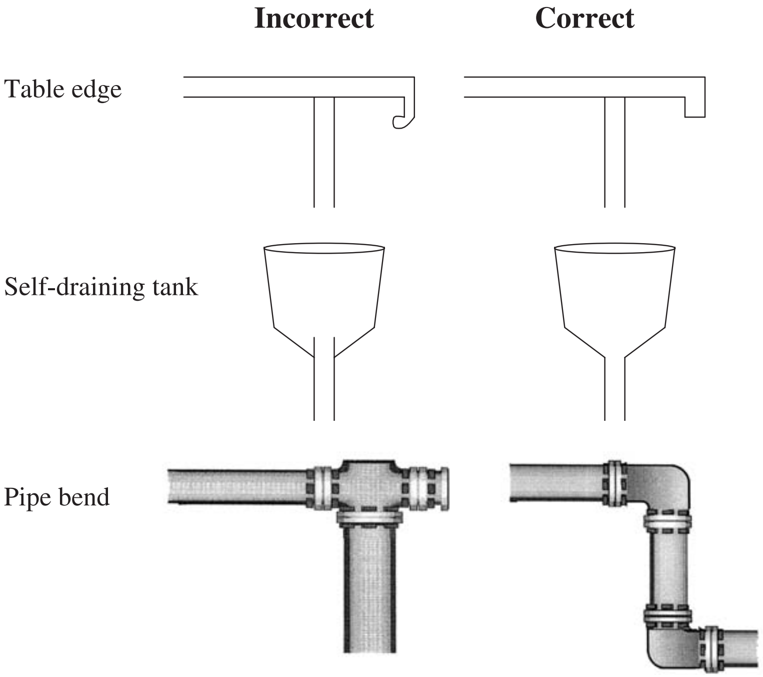


Figure 11.19. *Examples of Equipment Designs that Allow Proper Cleaning.*

- The exterior of non-product contact surfaces (processing equipment, floors, walls) should be arranged to prevent harboring of bacteria, pests, etc.

Meat is a perishable food item because it contains all the nutrients required for microorganisms to grow, and its pH (5.5–6.5) is not inhibitory to most microorganisms. The extensive fabrication, handling (some reports show that ground meat can be handled 10–15 times before it gets to the consumer) and distribution of raw and processed meat further increases exposure to microbial contamination. As previously discussed, some of the principal contamination sources encountered during processing are the slaughtering and evisceration processes. Live healthy muscle is essentially free of microorganisms; however, after slaughtering, natural defense mechanisms cease to function. During slaughtering, the knives/blades that cut through the skin can transfer microorganisms into the bloodstream. Because blood circulation is not immediately stopped, some microorganisms can still be distributed throughout the carcass. It is important to realize that 1 g of soil (dirt or manure) attached to the skin or feathers can contain 1 billion microorganisms. Evisceration or removal of the digestive tract is another major point. The digestive tract harbors high numbers of microorganisms (e.g., not uncommon to have about 200 million microorganisms/g). If the gut is ruptured and its contents spilled on the carcass, high contamination levels can be expected. Other potential contamination sources include people handling the meat, surrounding air, water used to rinse the carcasses, contact with equipment, insects, rodents, etc. Care should be given to common equipment (e.g., knives) used manually or on an automatic cut-up line during portioning and mixing. All surfaces in contact with the meat should be periodically cleaned and disinfected (e.g., a common practice for a manual cutting operation is dipping knives in a >80°C water bath). Personal hygiene of the employees should be enforced at all times. This should include measures such as hair nets (mandatory in most food processing plants), clean gloves, aprons and coats, absence of jewelry and mandatory hand washing before starting work. In some specialized operations, such as packaging of cooked products, employees might be required to cover their noses and mouths with a mask to minimize the spread of microorganisms. This is another measure taken to increase the shelf life of the product and reduce the risk of pathogens. Obviously, in such an operation, air filters for incoming air should be installed. Some plants maintain positive air pressure within the packaging room in order to prevent suction of air from other contaminated areas of the plant.

The method used for cleaning a food processing plant is based on the soil material present (Table 11.11). Because meat contains mainly protein, fat and moisture, alkaline solutions are the most common cleaning solutions used. Overall, various cleaning compounds are available on the market (Table

Table 11.11. Types and Characteristics of Soils Found in a Poultry Processing Plant. Adapted from Marriott (1999).

Soil	Solubility	Removal Ease	Changes Induced by Heating
Monovalent salts	Water soluble, acid soluble	Easy to difficult	Interaction with other compounds; subsequent removal difficulty
Divalent salts	Water insoluble	Can be difficult	Scale formation
Sugar	Water soluble	Easy	Carmelization; removal difficulty
Fat	Water insoluble, alkali soluble	Difficult	Polymerization; removal difficulty
Protein	Water insoluble, slightly acid soluble, alkali soluble	Very difficult	Denaturation; extreme removal difficulty

11.12). Usually, an alkaline solution, such as 1.5% sodium hydroxide, is used to saponify the fat and also dipeptidize the protein deposits. Various alkaline phosphates and synthetic detergents are also used in meat processing plants to remove meat deposits, fat and dirt. They are later washed away with water and the remaining scale deposits are removed with a weak/strong acid. Another approach to cleaning involves the use of enzymes, where a solution containing proteases (i.e., to break down protein deposits) is used in a mild alkaline solution (to saponify the fat deposits). The advantage of using enzymes is a reduction in corrosion of the plant equipment. Because the alkalinity of

Table 11.12. Categories of Cleaning Compounds on the Market.

Type	Activity	Examples
Alkali	Strong	Caustic (pH ≈ 13) Silicates Carbonates
Alkali	Weak	Phosphate Bicarbonate
Neutral		Water
Acidic	Weak	Citric
Acidic	Strong	Phosphoric Muriatic
Synthetic detergents		Anionic Cationic Nonionic

an enzyme solution cannot be too high (i.e., otherwise it will inactivate the enzymes) and water temperature is low, corrosion problems are minimized. However, it should be noted that enzyme solutions are not as popular today for general use because they are more expensive and present a higher risk to the people using them.

The cleaning steps commonly used in a meat plant include the following:

- Remove heavy soils from surfaces. This step is usually done manually (e.g., scrapers to remove meat chunks) to help reduce soil loads and later save on cleaning compounds and wastewater treatment.
- Rinse with water, usually, high-pressure hoses facilitate this step. The water temperature should be below 55°C to prevent cooking the meat onto the surface.
- Wash with an alkaline solution or a synthetic detergent, and apply a chemical compound(s) to break down the soil depositions. It is important to allow sufficient time for the chemical cleaning reaction(s) to take place. Usually, a contact time of 5–10 minutes is recommended at a water temperature of 50–55°C. When vertical surfaces are cleaned, foaming agents are used to keep the cleaning compound in close contact with the surface. Enzyme solutions can also be applied at this stage; however, lower water temperature should be used to prevent enzyme inactivation.
- Rinse with clean water to remove all the alkaline or detergent solutions.
- Acid wash to remove scale deposits. Mineral deposits are usually not removed by the alkaline cleaning solution, and therefore, acids (phosphoric, hydrochloric or organic acids such as citric, gluconic) are used to remove mineral deposits that can appear as a rusty or whitish scale.
- Inspect all surfaces to ensure the removal of all the soil and cleaning compounds.
- Sanitize the plant. It is crucial to start this step only after all the equipment is thoroughly cleaned. Otherwise, the sanitizer could not be in close contact with the surface, and its activity will be diminished. A chlorine solution (100–200 ppm), iodine (20–30 ppm) or quaternary ammonium solution (150–200 ppm) are commonly used.
- Rinse and dry to remove the sanitizer residues. However, some sanitizers such as quaternary ammonium have a prolonged residual effect and can be left on the equipment.
- Oil areas/equipment subject to corrosion.

Cleaning-in-place (CIP) is not popular in most parts of a meat plant because of plant design and the equipment used. However, where applicable (e.g., a closed system such as a smokehouse, some conveyor belt operations), CIP cleaning using heavy duty detergents can be used to effectively remove soil deposits without exposing employees to harsh chemicals.

SAMPLING AND MICROBIOLOGICAL CRITERIA

The concept of applying microbial limits to foods to establish safety criteria was suggested at the beginning of the 20th century (see review by Elliott and Michener, 1961). An example was hamburger meat where a limit for aerobic plate count was suggested at 10^6 cfu/g. Other products, such as raw and pasteurized milk, were included in the list and suggestions for certain limits were proposed. Later, the Codex Allimentarious Commission (1981) established international standards that helped eliminate confusion and determine an international language. Overall, two main microbial criteria are commonly used. The first is mandatory and refers to a standard that limits pathogens of public health concern; however, limits for nonpathogens may also be included. A mandatory standard is regarded as part of a regulation that is enforced by a government agency. The second microbial criteria is an advisory criterion (a guideline applied in food establishments during or after processing). It is used to monitor a certain microbial hygiene specification intended to increase assurance that a certain hygienic level has been met (Jay, 2000).

The Codex identifies five components for a microbial criterion. They consist of a statement of the organisms of concern, the analytical methods for their detection, a sampling plan, microbial limits for the particular food in question and the number of sample units that should confirm those limits.

The sampling plan is actually a statement of the acceptance criteria applied to a certain lot, based on applying a specified method to a predetermined number of sample units. It should include a sampling procedure, decision criteria and maybe a two-or three-class plan.

A two-class plan consists of the following:

(*1*) *n:* The number of sample units (e.g., chicken wings, packages) from a lot that must be checked to satisfy the requirement for a given sampling plan.

(*2*) *m:* The maximum number of bacteria per gram. Numbers above this level are either marginally acceptable or unacceptable. This is used to separate acceptable from unacceptable lots in a two-class plan. In a three-class plan, the *m* is used to separate good quality from marginally acceptable quality foods. In a two-class plan, it is common to assign $m = 0$, while in a three-class plan, *m* is usually a number above 0.

(*3*) *c:* The maximum acceptable number of units that may exceed the microbial criterion *m*. When this number is exceeded, the lot must be rejected.

(*4*) *M:* This is used only in a three-class plan as a quantity that is used to separate marginally acceptable quality from unacceptable quality foods. Values at or above *M,* in any sample, are unacceptable relative to sanitation indicators, spoilage potential or health hazards. A value determined for any one sample unit that is greater than *M* renders the whole lot as unacceptable and must be rejected. A two-class plan is simpler than a three-class plan and may be used to accept or reject a large lot in the presence/absence decision by a plan such as $n = 5$, $c = 0$, meaning that five individual units of the lot will be examined and none can contain a certain bacteria (e.g., *Salmonella*) in order for the lot to be accepted. If it is desired that two of the five samples may contain coliforms, in a presence/absence test, the sampling plan would be $n = 5$, $c = 2$. The presence/absence situation is generally obtained for a pathogen such as *Salmonella,* and an allowable upper limit for an indicator organism such as coliforms is more often the case. If it is desired to allow up to 100 coliforms/g in two of the five units, the sampling plan would be $n = 5$, $c = 2$, $m = 10^2$.

An example of suggested guidelines for deboned poultry products is given in Table 11.13.

In a three-class plan, the decision to accept or reject a lot is based on the following:

(*1*) $n = 5$: meaning that five individual units of the lot will be checked for aerobic plate counts and other specific bacteria. Note that all samples must be free of *Salmonella* by the method of examination in order for the lot to be acceptable. If any unit is positive, the entire lot is rejected.

(*2*) $c = 3$: means that three out of the five units checked for aerobic plate count (APC) of a product to be heated before serving (first row Table 11.13) may contain 10^4 cfu/g. If one unit has 10^5 cfu/g, the lot is rejected. For *E. coli* (last row in Table 11.13), two out of the five samples may contain *E. coli* which is indicated as $n = 5$, $c = 2$. An allowable upper limit for this indicator organism is 10 *E. coli*/g in two of the five units. After the five units have been examined for coliforms, the lot is acceptable if no more than two of the five units contain as

Table 11.13. An Example of Suggested Guidelines for Microbial Criteria of Further Processed Deboned Poultry Meat. Adapted from Warburton et al. (1988).

Tests/Conditions	*n**	*c*	*m*	*M*
APC* (heat before serving)	5	3	10^4	10^5
APC (cook before serving)	5	3	10^6	10^7
APC (bring to boil before serving)	5	3	10^5	10^6
S. aureus	5	1	10^2	10^4
E. coli	5	2	10	10^2

Note: no *Salmonellae, Yersinae* or *Campylobacters* allowed. *See text for abbreviations.

> many as 10 *E. coli*/g. The lot is rejected if three or more of the five units contain 10 *E. coli*/g, or if any one unit contains 100 cfu/g. Such a sampling plan may be made more stringent by increasing the *n* to 10 or by reducing the *c* to 1.

The decision to employ a two- or three-class plan is usually determined by whether presence or absence tests are desirable. If count or concentration tests are desired, a three-class plan is preferred. The three-class plan offers the advantage of being less affected by nonrandom variations among sample units, and of being able to measure the frequency of values in the *m* to *M* range.

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CHAPTER 12

Hazard Analysis Critical Control Points (HACCP)

INTRODUCTION

THE use of HACCP in food processing plants represents a scientific approach to controlling and reducing illnesses that might be related to food consumption. The HACCP concept was developed in the early 1970s by scientists at the Pillsbury Company while developing food for the National Aeronautic and Space Administration (NASA) and the U.S. Army Research Laboratory. The idea was developed because the commonly used random finished product testing could not guarantee the safety level required for the space program (it is very expensive to treat foodborne illness in space). An added benefit was the possible identification of the problem(s) at the early stage of the production scheme, which could save time, money and obviously reduce the risk level. The program was first applied to low-acid canned food, but since then, it has been applied to a large variety of foods, including those used in retail and the food service area. Today, it is not uncommon to hear about fast-food companies requiring their suppliers to be HACCP approved and declining to purchase supplies from nonapproved plants. This overall approach (also seen in car manufacturing, etc.) results in the entire production and marketing systems working together to assure high quality. Various countries have mandated the use of HACCP in parts/all of their food processing plants, while others have recommended HACCP implementation in order to facilitate inspection. Becoming a HACCP-approved processing plant requires substantial planning and investment in resources (e.g., people, money); however, a good HACCP plant can justify such costs. Some people joke about the HACCP acronym and call it “hard, agonizing, complicated, confused paperwork,” but once in place, it can actually improve production, safety and quality control on a continuous basis.

A good HACCP system is one that leads to the production of microbiologically safe food by using a systematic approach of monitoring production from raw materials through all stages of processing, storage and distribution. The following chapter will describe the seven HACCP principles that have been internationally accepted and described in the Codex Alimentarius Commission

Codex (1993) and the National Advisory Committee on Microbiological Criteria for Foods (Mortimore and Wallace, 1995). In addition, three generic models (poultry slaughter, cooked turkey product, battered and breaded chicken fillets) suggested for use by the poultry industry are described. The models illustrate the use of a HACCP plan and should also assist the reader in obtaining more information about processes described in earlier chapters, including primary processing of live birds (Chapter 4), preservation (Chapter 7), preparation of poultry products (Chapter 9) and microbiology (Chapter 11).

Overall, different food processing companies have or are currently implementing HACCP and ISO 9000 programs into their businesses and experiencing tangible benefits in areas such as compliance with legislation, consistent product quality, increased product safety and third-party acceptance of performance. Some of the new schemes are actually aimed to simultaneously implement HACCP and ISO 9000, because the two systems are complimentary to each other (Griffiths and Barbut, 2000; Sandrou and Arvanitoyannis, 1999).

THE SEVEN HACCP PRINCIPLES

(*1*) *Assess the hazards and risks* that may be evaluated for individual food ingredients using a flow diagram (see example in Figure 12.1) or ranking the finished food product and assigning it a certain rating.

(*2*) *Determine the critical control points (CCP)* by using a decision tree (Table 12.1). A CCP is defined as any point or procedure in a food production system where control can be exercised and a hazard can be minimized or prevented. A typical CCP can consist of the following:

- heat process where time and temperature relations must be maintained to destroy a specific pathogen
- freezing and time to freeze before pathogens can grow
- maintainance of a certain pH at a level that prevents pathogen growth
- employee hygiene

Overall, two types of CCPs are recognized: the first is to ensure controlling a hazard and the second is to minimize a hazard.

(*3*) *Establish the critical limits* with one or more prescribed tolerances that must be met to ensure that a CCP effectively controls a microbiological, chemical or physical hazard. This could mean making sure that a certain minimum destructive temperature is achieved and maintained long enough to inactivate a certain pathogen. For example, the USDA indicates that the minimum internal temperature required for cooking perishable, uncured meat and poultry products should be 71.1°C (160°F). Another critical limit can be established for keeping refrigeration temperatures within a certain specific and narrow range.

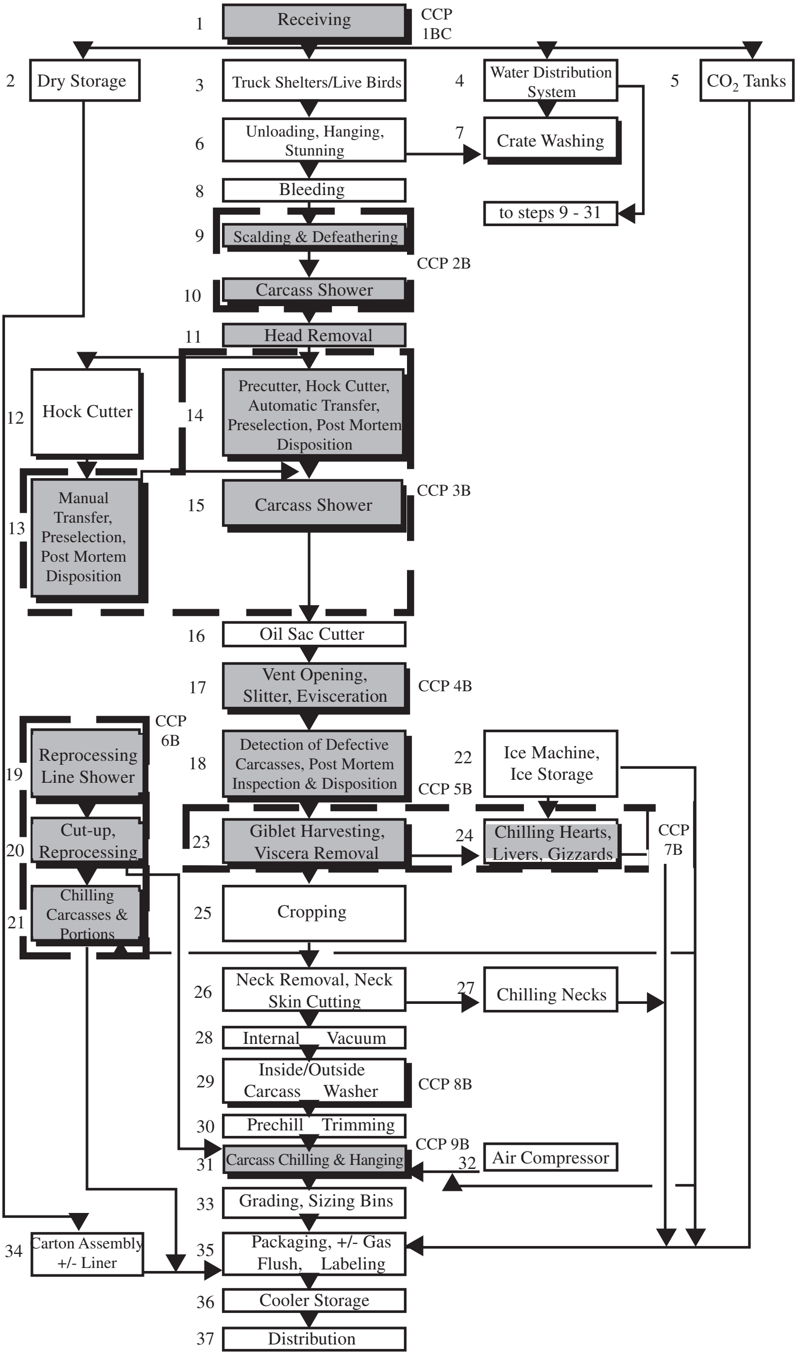
1 Receiving
CCP 1BC
2 Dry Storage
3 Truck Shelters/Live Birds
4 Water Distribution System
5 CO_2 Tanks
6 Unloading, Hanging, Stunning
7 Crate Washing
8 Bleeding
to steps 9 - 31
9 Scalding & Defeathering
CCP 2B
10 Carcass Shower
11 Head Removal
12 Hock Cutter
14 Precutter, Hock Cutter, Automatic Transfer, Preselection, Post Mortem Disposition
13 Manual Transfer, Preselection, Post Mortem Disposition
15 Carcass Shower
CCP 3B
16 Oil Sac Cutter
17 Vent Opening, Slitter, Evisceration
CCP 4B
CCP 6B
19 Reprocessing Line Shower
18 Detection of Defective Carcasses, Post Mortem Inspection & Disposition
CCP 5B
22 Ice Machine, Ice Storage
20 Cut-up, Reprocessing
23 Giblet Harvesting, Viscera Removal
24 Chilling Hearts, Livers, Gizzards
CCP 7B
21 Chilling Carcasses & Portions
25 Cropping
26 Neck Removal, Neck Skin Cutting
27 Chilling Necks
28 Internal Vacuum
29 Inside/Outside Carcass Washer
CCP 8B
30 Prechill Trimming
CCP 9B
31 Carcass Chilling & Hanging
32 Air Compressor
33 Grading, Sizing Bins
34 Carton Assembly +/- Liner
35 Packaging, +/- Gas Flush, Labeling
36 Cooler Storage
37 Distribution

Figure 12.1. *Process Flow Diagram for a Chilled, Ready-to-Cook Whole Chicken, Including Suggested Critical Control Points (CCP) Marked as Shaded Areas. From CFIA (1998a).*

Table 12.1. An Example of Using a Decision Tree Approach for a HACCP Model. Adapted from Mortimore and Wallace (1995).

Question 1: Is there a hazard associated with this raw material?

No—proceed to the next raw material.

Yes—go to question 2.

Question 2: Is the plant or the customer going to process this hazard out of the product (e.g., heat, radiation treatment)?

No—sensitive raw material requiring high level of control. Establish a Critical Control Point.

Yes—go to question 3.

Question 3: Is there a cross-contamination risk to the facility or to other products that will not be controlled?

No—proceed to the next raw material.

Yes—sensitive raw material. Establish a Critical Control Point.

(*4*) *Establish procedures to monitor the CCPs* by scheduling testing or observation of each identified CCP and its limits. The result must be documented and kept on record for a predetermined time (e.g., some inspection agencies require keeping information for up to five years and making it available upon request). For monitoring processing parameters such as temperature, a chart recorder may be installed to show that a certain cooking temperature has been achieved. Other physical or chemical parameters such as water activity and pH can also be monitored.

(*5*) *Establish corrective actions* to be taken when deviations occur in the CCP monitoring. The actions should eliminate the hazard created by deviation from the plan. If the hazard cannot be removed and the product may be unsafe, the product should be removed. In general, the action(s) must show that the CCP was brought under control.

(*6*) *Establish effective record systems,* which is a crucial step in running the program. The entire HACCP plan must be kept on file at the plant and must be available to the official inspector upon request. Examples of forms used for recording and documenting are provided later in the chapter. Some inspection agencies provide standard forms, while others let the establishment develop its own forms that have to be approved by the inspection branch. Overall, the forms should provide documentation for all ingredients, processing, storage and distribution steps.

(*7*) *Establish procedures for verification that the HACCP system is working* or, in other words, make sure that the HACCP system is working correctly. Verification consists of procedures and tests to determine that the system is in compliance with the prescribed plant. The verification process should also confirm that all hazards have been identified when the HACCP plan was developed. Some of the verification measures may include compliance with a set of established microbiological criteria provided by either government or industry bodies. The procedure should include activities such as inspection schedules, reviews of the HACCP plan, a check of CCP records and any deviations, random sample collection and written record verification. The reports should also include the name(s) of the designated person(s) responsible for administration, monitoring data, certification and calibration, as well as those responsible for dealing with deviations. Scheduled or random checking, such as inserting a metal piece in a box of finished goods to be passed through a metal detector, can represent part of the evaluation plan.

HACCP MODELS

Various models have been developed to control hazards in the food industry. Below, you will find three generic models that have been proposed as working blueprints for three processed poultry products. The idea behind developing the generic models is to provide the individual processor with examples and suggested starting points. The United States Department of Agriculture (USDA) published a final rule in July 1996 mandating that HACCP be implemented as the system of process control in all USDA-inspected meat and poultry plants. As part of its effort to assist establishments in the preparation of plant-specific HACCP plans, the Food Safety and Inspection Service (FSIS) determined that a generic model for each process defined in the regulation be made available for use by the industry. After a few revisions of the models and regulations, the USDA published an up-to-date document concerning the generic models (USDA, 1999), which is designed to be used with the list of process categories found in the HACCP regulations in section 417.2 (b)(1). Overall, as stated in the document, generic HACCP plans serve as useful guidelines; however, it is impossible for a generic model to be developed without it being too general. Therefore, it is incumbent on each plant's HACCP Team to tailor the model to fit products in each plant, based on knowledge about the process. Several points should be considered when using a model to develop specific HACCP plans.

All plants shall have Sanitation Standard Operating Procedures (SSOPs). Good Manufacturing Practices (GMPs) and Standard Operating Procedures (SOPs) may be in place as the foundation of the HACCP program. GMPs are minimum sanitary and processing requirements applicable to all companies processing food. SOPs are step-by-step directions for completing important plant procedures, and should specifically describe the method for conducting and controlling the procedure. SOPs should be evaluated regularly (e.g., daily, weekly) to confirm proper and consistent application and should be modified as necessary to ensure control. Each generic model can be used as a starting point for the development of a plant-specific plan reflecting the plant environment and the specific processes conducted. The generic models are not intended to be used “as is” for a plant-specific HACCP procedure.

POULTRY SLAUGHTER—A GENERIC HACCP MODEL

This is an example of a generic model proposed by the Canadian Food Inspection Agency for chilled, ready-to-cook, whole chicken (CFIA, 1998a). The model has a lot in common with the USDA model, but it elaborates on a few more issues. The Poultry Slaughter Model encompasses the process starting from receiving the live bird (model written for chickens, but can be applied to turkeys, ducks, etc.) through packaging the whole bird. The illustration will take the reader step by step, demonstrating the potential hazards and ways to control them.

The process flow diagram (Figure 12.1) shows the different raw materials and processes involved in obtaining the final product. The product description includes the following:

- product name—chilled ready-to-cook poultry (whole and portions, including giblets)
- important product characteristics (pH, a_w)—none
- how the product will be used—cooked before serving
- packaging—fully lined boxes or modified atmosphere packaging
- shelf life—about 7 days at 4°C or less
- where it will be sold—retail, hotel restaurant institution (HRI), and further processors
- labeling instructions—keep refrigerated, safe handling instructions (recommended)
- special distribution control—≤4°C at all times

The meat is obtained from the live bird.

The non-meat components include water and possibly CO_2 for modified atmosphere packaging.

Packaging material can include absorbent pads, plastic film wrap, polyliners, waxed cardboard cartons and plastic bags.

Bacteriological agents that may be used during the process include chlorine, sodium chloride, phosphate and lactic acid.

It is recognized that the different processes involved (previously described in Chapter 4) cannot eliminate all pathogenic bacteria; however, research findings have indicated that certain procedures can reduce the bacterial load on ready-to-cook poultry meat. Some of the most important preventive measures include the following:

- Adequate feed withdrawal can reduce evisceration accidents.
- Effective spray washing of the carcasses with sufficient water (volume and pressure) can remove about .5–1 log (i.e., up to 90%) of the bacterial load.
- Effective re-processing or decontamination procedures can reduce visible and bacterial contamination.
- Rapid chilling and maintaining the temperature ≤4°C will minimize bacterial growth.
- Using countercurrent scalders can reduce the bacterial load.
- Incorporating a sanitizing agent such as chlorine, hot water or lactic acid during whole-carcass spray wash can help to reduce the bacterial load.
- Treating product transfer belts and automatic evisceration equipment with water sprays for cleaning during continuous operation can reduce bacteria.
- Operating counter-flow water chillers can reduce the bacterial load.
- Adding bactericidal agents such as chlorine or phosphate to water chillers can also help.

As can be seen in Figure 12.1, provisions have been made for different processing schemes, such as using manual vs. automatic carcass transfer (steps 12 and 13 versus step 14). Plants equipped with new technology eviscerators (e.g., separation of viscera from carcass; see also Figure 4.12) should get government approval for a specific HACCP plan that incorporates such a step (e.g., step 23).

Table 12.2 lists the potential biological, chemical and physical hazards that might be a problem during processing. It is extremely important to try and identify all the potential problems so adequate measures can be taken to minimize them. The table also lists the suggested critical control points and numbers them in sequential order. For example, the first critical control point is listed for receiving the raw material and is identified as CCP 1BC, meaning that this is the first point that might represent biological (B) and chemical (C) hazards.

Table 12.3 lists the different biological hazards that are not controlled by the operator and ways they can be addressed.

Table 12.4 shows a step-by-step procedure for dealing with the critical control points.

Table 12.5 is an example of a record-keeping form for the scalding, defeathering and carcass shower.

Table 12.6 is an example for the carcass inside/outside washer and chilling process.

COOKED PRODUCT—A GENERIC HACCP MODEL

This is an example of a generic model proposed by the Canadian Food Inspection Agency for a cooked meat product (CFIA, 1998b), and was adopted

Table 12.2. Biological (B), Chemical (C) and Physical (P) Hazards and Suggested Critical Control Points (CCP) Related to Ingredients, Incoming Material, Processing and Product. See also Figure 12.1 Showing Process Flow for a Chilled Ready-to-Cook Whole Chicken. From CFIA (1998a).

Identified Biological Hazards (Bacteria, Parasites, Viruses, etc.)	Control Point(s)
Incoming Materials	
Live chicken: insufficient feed withdrawal, crop and digestive system full of food contents (e.g., *E. coli* sp.)	Step #1, Receiving See Table 12.3
Live chicken: presence of nonsporulating bacteria (*Salmonella* sp., *E. coli* sp., *Campylobacter* sp., *Yersinia enterocolitica, Listeria monocytogenes*)	See Table 12.3
Live chicken: presence of sporulating bacteria (*Clostridium perfringens*)	See Table 12.3
Water: not meeting the drinking water criteria established by the government	Prerequisite programs (water)
Process Steps	
#1 Reception of noncompliant material—see above	CCP-1BC
#2 Dry storage: pathogenic bacterial contamination of packaging material during storage due to improper handling causing damaged containers and exposed product	Prerequisite programs (sanitation, employee training)
#4 Water distribution system: pathogenic bacterial contamination due to back-siphonage or dead ends	Prerequisite programs (equipment)
#7 Crate washing: pathogenic bacterial contamination of subsequent noncontaminated birds/flocks	Prerequisite programs (equipment, employee training, sanitation)
#8 Bleeding incision: pathogenic bacterial contamination of the bleeding surfaces	Prerequisite programs (equipment, employee training, sanitation)
#9, 10 Scalding and defeathering (picking) and carcass shower: • spread of pathogens from carcass to carcass by contaminated scald water and picker fingers. • muscle contamination due to breakage of the skin barrier. • inadequate removal of external visible contamination and loosely attached bacteria	CCP-2B
#11 Head removal: pathogenic bacterial contamination of necks due to buildup of organic debris and heads on head puller	Prerequisite programs (equipment, employee training, sanitation)

Table 12.2. (continued)

Identified Biological Hazards (Bacteria, Parasites, Viruses, etc.)	Control Point(s)
#12 Hock cutter: pathogenic bacterial contamination of cut surfaces due to faulty cleaning of equipment during operations	Prerequisite programs (equipment, sanitation)
#13 Manual transfer/rehang and preselection: pathogenic bacterial contamination from bird-to-bird contact and from cloacal leakage	CCP-3B
#13 Preselection: • inadequate detection/removal of obviously condemnable carcasses by company employee(s). • ineffective monitoring of employee performance by plant supervisor	CCP-3B
#13 Postmortem disposition: failure by government veterinarian to ensure that carcasses requiring condemnation are condemned	Government responsibility See Table 12.3
#14 Precutter, hock cutter, automatic transfer: pathogenic bacterial contamination of the cut surfaces due to faulty cleaning of equipment during operations	CCP-3B
#14 Preselection: inadequate detection/removal of obviously condemnable carcasses by company employee(s); ineffective monitoring of employee performance by plant supervisor	CCP-3B
#14 Postmortem disposition: failure by government veterinarian to ensure that carcasses requiring condemnation are condemned	Government responsibility See Table 12.3
#15 Carcass shower: inadequate removal of external visible contamination and loosely attached bacteria	CCP-3B
#16 Oil sac cutter: pathogenic bacterial contamination of cut surfaces and cross contamination from bird to bird due to faulty cleaning of equipment during operations	Prerequisite programs (equipment, sanitation, employee training)
#17 Vent opening, slitter and eviscerator: fecal contamination and spread of pathogens due to inadequate feed withdrawal	Prerequisite programs (employee training); see Table 12.3
#17 Vent opening, slitter and eviscerator: fecal contamination and spread of pathogens due to improper equipment operation, faulty operational cleaning of automatic equipment or deficient sanitizing of backup employee's hands or tools	CCP-4B

(continued)

Table 12.2. (continued)

Identified Biological Hazards (Bacteria, Parasites, Viruses, etc.)	Control Point(s)
#18 Detection of defective carcasses: failure by company employee(s) to detect carcasses with deficiencies and handle as per prescribed procedures	CCP-5B
#18 Detection of defective carcasses: cross contamination and spread of pathogens due to improper handling between rejected carcasses/portions and approved carcasses/portions and carcasses/portions passed for reprocessing	CCP-5B
#18 Government postmortem inspection and/or oversight: failure by government inspectors to effectively perform postmortem inspection and/or to effectively verify the detection and correct handling of defective carcasses by company employees	See Table 12.3
#18 Postmortem disposition: failure by government veterinarian to ensure that carcasses requiring condemnation are condemned and to verify that other defective carcasses are handled correctly	See Table 12.3
#19 Reprocessing line carcass shower: failure to remove visible contamination and loosely attached pathogens from external surfaces	CCP-6B
#20 Reprocessing/cut-up: spread of contamination onto cut surfaces, failure to effectively remove contamination	CCP-6B
#21 Chilling salvaged portions: temperature abuse/ bacterial growth due to inadequate temperature reduction	CCP-6B
#22 Ice machine and storage: Listeria sp. contamination due to deficient sanitation	Prerequisite programs (sanitation)
#23 Giblet harvesting and viscera removal: fecal and ingesta contamination of carcasses or giblets due to improper equipment operation or to faulty operational cleaning of automatic equipment or cleaning/sanitizing of employee's hands or tools	CCP-7B
#24 Chilling hearts, livers and gizzards: temperature abuse/bacterial growth due to inadequate temperature reduction	CCP-7B
#25 Cropping: full crops causing spillage of crop contents	See Table 12.3
#25 Cropping: spread of crop contamination due to improper operational cleaning of equipment	Prerequisite programs (equipment and sanitation)

Table 12.2. (continued)

Identified Biological Hazards (Bacteria, Parasites, Viruses, etc.)	Control Point(s)
#26 Neck and neck skin removal: cross contamination with crop contents due to faulty cleaning of automatic equipment during operations or deficient cleaning/sanitizing of employee's hands or tools	Prerequisite programs (equipment and sanitation)
#27 Neck chilling: temperature abuse/bacterial growth due to inadequate temperature reduction	Prerequisite programs (equipment)
#28 Internal vacuum: cross contamination due to faulty cleaning of equipment during operations	Prerequisite programs (equipment and employee training)
#29 Inside/outside carcass washer: failure to remove visible contamination and loosely attached bacteria from external surfaces and internal cavity	CCP-8B
#30 Prechill trimming: spread of contamination on cut surfaces, failure to remove affected portions (pathology and contamination)	Prerequisite programs (employee training) and FPS
#31 Carcass chilling and hanging: spread of pathogens and bacterial growth due to inadequate temperature reduction	CCP-9B
#32 Air compressor: pathogenic bacterial contamination due to inadequate cleaning of plastic air lines on countercurrent chillers or lack of air filter	Prerequisite programs (sanitation, equipment)
#33 Grading, sizing bins: cross contamination by employees and equipment	Prerequisite programs (equipment, employee training, sanitation)
#35 Packaging +/− gas flushing and labeling: Cross contamination by equipment or employees, growth of pathogens due to insufficient levels of CO_2; incorrect packing/slaughter date	Prerequisite programs (equipment, employee training)
#36 Cooler storage: growth of bacterial pathogens due to time/temperature abuse	Prerequisite programs (storage control)
#37 Distribution: growth of bacterial pathogens due to time/temperature abuse	See Table 12.3
Identified Chemical Hazards	**Control Point(s)**
Incoming Materials	
Live chicken: residues (antibacterial, pesticides)	See Table 12.3
Water: chemical contamination of water supply	Prerequisite programs (water)

(continued)

Table 12.2. (continued)

Identified Chemical Hazards	Control Point(s)
Carbon dioxide (CO_2): usage of wrong or contaminated gas	Step #1, Receiving
Packaging material: absorbent pads, plastic film wrap, plastic breast tags, polyliners, waxed cardboard; non-food-grade material, remigration of chemical components	Step #1, Receiving
Bacteriocidal agents (chlorine, phosphate): non-food-grade or not accepted by the government	Step #1, Receiving
Process Steps	
#1 Reception of noncompliant material: see above	Step #1, Receiving CCP-1BC
#9 Chemical residue in scalding tanks due to improper cleaning/drainage	Prerequisite programs (sanitation)
#13 Chemical residue on transfer table due to improper cleaning/drainage	Prerequisite programs (sanitation)
#31 Chemical residue in chill tanks due to improper cleaning/drainage	Prerequisite programs (sanitation)
#32 Air compressor: contamination with oil droplets due to missing or overloaded air-line filter	Prerequisite programs (maintenance)
#33 Chemical residue in sizing bins due to improper cleaning/drainage	Prerequisite programs (sanitation)
#35 Chemical residue in packaging tables due to improper cleaning/drainage	Prerequisite programs (sanitation)
Identified Physical Hazards	Control Point(s)
Process Steps	
#2 Dry storage: incidental material from storage and the environment	Prerequisite programs (sanitation, employee training)
#4 Water distribution system: metallic particles from scale deposits within the pipes	Prerequisite programs (equipment)
#33 Grading, sizing bins: plastic particles implanted in carcasses from defective breast tags and improper tagging practices	Prerequisite programs (employee training)
#34 Carton assembly and liner insertion: incidental material due to faulty handling procedures	Prerequisite programs (employee training, equipment)

Date: ______________ Approved by: ______________________________

Table 12.3. Biological (B) Hazards, for Chilled, Ready-to-Cook Whole Chicken, that are not Controlled by the Operator. From CFIA (1998a).

Identified Hazards	The Way the Hazard Could be Addressed (Cooking Instructions, Public Education, Use Before Date, etc.)
Incoming Materials	
Live young chicken (B): nonsporulating pathogenic bacteria (*Salmonella* sp., *E. coli* sp., *Campylobacter* sp., *Yersinia enterocolitica, Listeria monocytogenes*) and sporulating pathogenic bacteria (*Clostridium perfringens*)	Grower's responsibility to reduce pathogenic bacteria contamination during production (Salmonella). Grower's responsibility to ensure an adequate feed withdrawal period. Personnel preparing food must ensure that poultry meat is thoroughly cooked, that cooked poultry is not recontaminated or subjected to time/temperature abuse and that raw poultry meat or its juices do not cross contaminate other food
Live young chicken: residues (antibacterial, pesticides)	These hazards should be controlled by the growers
Process Steps	
#13 Postmortem disposition (B): Failure by government veterinarian to ensure that carcasses requiring condemnation are condemned	Responsibility of government
#14 Postmortem disposition (B): Failure by government veterinarian to ensure that carcasses requiring condemnation are condemned	Responsibility of government
#17 Vent opening, slitter and eviscerator contamination due to inadequate feed withdrawal (B)	Feed withdrawal is grower's responsibility
#18 Postmortem inspection or detection by plant employees (B): failure by government inspectors to perform postmortem inspection or to effectively verify the detection and correct handling of defective carcasses by company employees	Responsibility of government
#18 Postmortem disposition (B): Failure by government veterinarian to ensure that carcasses requiring condemnation are condemned and that other defective carcasses are handled correctly	Responsibility of government

(continued)

Table 12.3. (continued)

Identified Hazards	The Way the Hazard Could be Addressed (Cooking Instructions, Public Education, Use Before Date, etc.)
#25 Cropping: Full crops causing spillage	Feed withdrawal is grower's responsibility
#37 Distribution (B): biological growth of pathogens due to temperature abuse	Driver/distributor to monitor temperature to be ≤4˚C. Retailer's responsibility to monitor temperature at receiving and within display. Consumers must also monitor temperature

Date: ____________ Approved by: ______________________________

by the author for cooked, sliced turkey ham, as an example of the many types of cured luncheon meat products on the market. Also, in this case, the model has a lot in common with the USDA (1999) model but elaborates on a few more issues. The model refers to ready-to-eat products that do not require further heating by the consumer. As the product is cured, different salts are added (e.g., sodium chloride, sodium nitrite, phosphate) and may be important in preserving the product (see Chapter 11). Proper refrigeration or freezing, after cooking, is also essential for the safekeeping of this ready-to-eat product.

The description of the product includes the following:

- product name—cooked, sliced turkey ham
- important product characteristics (pH, a_w)—salt: not less than X%; nitrite: X ppm (usually 100–200 ppm); phosphate
- use of product—sliced, ready-to-eat
- packaging—vacuum packaged
- shelf life—X days (e.g., 50 days) after slicing when kept at ≤4°C
- distribution—retail, food service
- labeling instructions—best before date, keep refrigerated
- special distribution control—under refrigeration or frozen

The process flow diagram is presented in Figure 12.2, which also suggests control points. The different processing steps involved in preparing such a cooked product have been described in Chapter 8, and a formulation for a turkey ham product is provided in Chapter 9.

Table 12.7 lists the potential biological, chemical and physical hazards that might be related to the raw ingredients and processing of the turkey ham. The biological hazards mainly include various microorganisms that might be found on the raw meat or transferred from workers in the plant to the meat. Of particular

Table 12.4. Detailed Description of Some Critical Control Points for Chilled Ready-to-Cook Whole Chicken. From CFIA (1998a).

Process Steps	CCP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#1 Receiving	CCP-1BC	Improper withdrawal causing full crop and intestines resulting in contamination of carcasses during evisceration	No distention of crop or intestines, evisceration accidents below "X%"; feedback to growers	Receiver check for contract specifications or letter of guarantee or receive farm-generated antemortem information, e.g., disease and medication history, time of feed withdrawal and loading; team manager records % of contaminated carcasses and cause and gives feedback to growers	Slaughter lot at end of shift; slow line speed, adjust equipment if evisceration accidents above "X%"	Quality Assurance (QA) verifies receiver procedures and evisceration performance once/wk and records	Receiver log, team manager record, QA record
		Non-food-grade plastic in packaging materials or breast tags or delivery of wrong gas or contaminated CO_2; bactericidal agents not food grade or not accepted by the government	Food-grade material or bactericidal agent; pure CO_2 used for each shipment, letter of acceptance from the government for bactericidal agent	Receiver check for contract specifications or letter of guarantee and record	Receiver rejects shipment or "holds" pending receipt of letter of guarantee	QA verifies receiving procedure once/month and records	

(continued)

Table 12.4. (continued)

Process Steps	CCP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#9 and #10 Scalding and defeathering carcass shower	CCP-2B	Pathogen contamination of carcasses from scald water or picker fingers; inadequate removal of contamination including loosely attached pathogens by shower	Minimum "X" liters make up water/ carcass into scalder; scald water temperature "X"˚C; continuous water spray/ rinse of fingers; shower water pressure minimum "X" bar; minimum "X" liter per carcass, coverage of the entire surface area and no torn skin; carcasses visibly free of all extraneous material	Operator to record scald water temperature and water usage and confirm water sprays functional in the pickers once/hour; operator to check shower performance at start of each lot change and record water pressure, volume and extent of carcass coverage each hour	Operator adjusts made up water volume, scald water temperature and picker water spray(s) volume; service person manually adjusts pressure and direction of water spray and repairs nozzles for carcass shower	Team manager verifies twice per shift and records; QA verifies once/month and records	Operator log; service person log, pre-op records; team managers record; QA record
#13 and #15 Precutter, hock cutter, automatic transfer, carcass shower	CCP-3B	Pathogenic bacterial contamination from carcass-to-carcass contact and buildup of organic debris on transfer belt/ table; inadequate removal of loosely attached bacteria and visible contamination by	Synchronization of kill and evisceration lines, no carcass accumulation on belt/ table (extra carcasses hung back on rack and rehung before skin is dry); complete carcass	Team manager monitors and records number of carcasses hung back and skin condition, carcass shower coverage, water pressure and if any loose material on	Team manager instructs/corrects carcass transfer employees, condemns dried carcasses and redirects shower nozzles to cover entire carcass; service person repairs nozzles	QA verifies line synchronization, preselection performance, shower(s) performance and bactericidal level once/day	Team manager log; QA record

Table 12.4. (continued)

Process Steps	CCP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
		carcass shower; inadequate detection/removal by company employee(s) of obviously condemnable carcasses that could contaminate the evisceration line, e.g., pendulous crop, ascites	and belt coverage by shower(s) with minimum "X" bar water pressure; carcass transfer chutes and tables maintained clean during operations by water sprays; correct concentration of bactericidal agent in spray water (e.g., 4% lactic acid), carcasses visibly free of all extraneous material; no obviously condemnable carcasses rehung on evisceration line	carcasses once/hour and after each lot change; service person tests and records concentration of bactericidal agent at startup and at each production break for carcass and belt showers; team managers monitors preselection of carcasses once/hour and records observations	and adjusts concentration of bactericidal agent		
#14 and #15 Precutter, hock cutter, automatic transfer, carcass shower	CCP-3B	Inadequate removal of loosely attached bacteria and visible contamination by carcass shower; inadequate detection/removal of obviously condemnable	Complete carcass coverage by shower(s) with minimum "X" bar water pressure; correct concentration of bactericidal agent in	Team manager monitors carcass shower coverage, water pressure and if any loose material on carcasses once/hour and after each	Team manager redirects shower nozzles to cover entire carcass; service person repairs nozzles and adjusts concentration of bactericidal agent;	Shower(s) performance and bactericidal level once/day; QA verifies employee treatment of fallen carcasses and preselection performance	Team manager log; QA record

(continued)

Table 12.4. (continued)

Process Steps	CCP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
		carcasses and unhygienic handling of fallen carcasses by back-up employee	spray water (e.g., 4% lactic acid); all obviously condemnable carcasses removed from evisceration line and fallen carcasses handled in a hygienic manner	lot change; service person tests and records concentration of bactericidal agent at startup and at each production break for carcass showers; team manager observes preselection and handling of fallen carcasses once/hour and records observations	Team manager instructs/retrains employee as necessary; reject carcasses handled in unhygienic manner	once/day and records	
#23 and #24 Giblet harvesting, viscera removal and giblet chilling	CCP-7B	Fecal and ingesta contamination of edible giblets, cross contamination by employees or equipment; bacterial growth due to time/temperature abuse	Edible giblets free of visible fecal/ingesta contamination; chill water maximum 4˚C; minimum “X” ppm of bactericidal agent	Team manager observes and records if equipment product surfaces maintained clean during operations and corrects employee harvesting procedures, e.g., wash hands/tools if contaminated; team manager to record chiller thermometer temperature every 30 minutes	Team manager condemns contaminated giblets and instructs/retrains employees as necessary and lowers giblet chiller water temperature; service person corrects equipment deficiencies	QA verifies operations once/shift and records; QA verifies chiller temperature gauge with digital thermometer 1/shift	Team manager records; QA records

Process Steps	CCP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#29 Inside/ outside carcass washer	CCP-8B	Failure to remove loosely attached bacteria and/ or visible contamination from carcass external surfaces and internal cavity	Carcasses visibly free of extraneous material, all nozzles operating and aligned to spray entire carcass, operating at "X" bar or higher; Minimum "X" liter/ carcass; Minimum "X" ppm bactericidal agent (e.g., 4% lactic acid)	Team manager to check and record shower carcass coverage and presence of extraneous material on washed carcasses 1/hour; at startup and at production breaks, service person to test concentration of bactericidal agent	Service person corrects water pressure, repairs defective equipment and adjusts alignment of nozzles and concentration of bactericidal agent	QA to verify shower performance and concentration of bactericidal agent twice per shift	Team manager records; QA bacteriological tests
#31 Carcass (water) chilling and hanging	CCP-9B	Pathogenic bacterial growth due to inadequate temperature reduction or water dilution	Prechiller maximum water temperature "X"°C, final chiller maximum water temperature 4°C, carcass temperature at exit 4°C or less, extraneous material limits as per FPS; Minimum "X" ppm bactericidal agent in chiller overflow water [Note: Use of bactericidal agent	Team manager to record chillers thermometer temperature every 60 minutes, record temperatures of five carcasses every "X" hour, carcasses/ minute and L/minute of makeup water; FPS person to conduct postchill checks; Service person to test and	Service person notified to lower prechiller/ chiller water temperature; CPIP person holds carcasses for further chilling, extraneous material as per CPIP program	QA verifies chiller temperature gauge with digital thermometer 1/shift; QA to verify once per shift makeup water volume, carcass internal temperature and concentration of bactericidal agents; QA to sample "X" carcass/week collected from drip line for, e.g., total *E. coli, Salmonella* sp.	FPS records; team manager and service person records; QA records, including bacteriological tests

(continued)

Table 12.4. (continued)

Process Steps	CCP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
			in carcass showers, chiller water and for (operational) rinsing of automatic evisceration equipment only required if product bacteriological test results are not in compliance with plant specifications based on government requirements. The efficacy of chlorine in carcass showers is questionable.]; Minimum 2 liter/carcass makeup is water	record concentration of bactericidal agent 1/hour and adjust feed rate as required			
#31 Carcass (air) chilling and hanging	CCP-9B	Pathogenic bacterial growth due to inadequate temperature reduction	Chain speed maximum "X" cm/min; air temperature maximum "X"°C; carcass temperature at exit 4°C or less; carcass extraneous material limits as per FPS standards	Team manager records chain speed, air and carcass temperature every "X" hour; FPS person to conduct postchill checks	Service person notified to lower air temperature; CPIP person hold carcasses for further chilling, extraneous material as per CPIP program	QA verifies and records air temperature and internal carcass temperature once per shift; QA to sample "X" carcasses/wk for e.g., total *E. coli* count, *Salmonella* sp.	FPS records; team manager and service person records; QA records including bacteriological tests

Date: ____________ Approved by: ____________________

Table 12.5. Example of a HACCP Record-Keeping Sheet for Scalding, Defeathering and Carcass Shower. From CFIA (1998a).

Date: ______ **Operator:** ______ **Shift:** ______ **QA Validation:** ______

		Scald Water		Picker Water Sprays		Carcass Shower			
Time	Number of Carcasses/ Minute	Volume (Liter/Minute)	Temperature (˚C)	Adequate Volume (Yes/No)	Water Temperature (˚C)	Water Pressure (Bar)	Complete Coverage (Yes/No)	Loose Extraneous Material (Yes/No)	Number Torn Skin/Minute
Comments:									

Table 12.6. An Example of a HACCP Record-Keeping Sheet—Carcass Inside/Outside Washer and Chilling. From CFIA (1998a).

Date: ______________________ **Team Manager:** ______________________

Shift: ______________________ **QA Verification:** ______________________

		Inside/Outside Carcass Washer				Carcass Shower			
	Line Speed	Water		Complete Carcass Coverage	Loose Extraneous Material	Prechiller Water Temperature	Chiller Water Temperature	Chiller Make-up Water Volume	Chilled Carcass Temperature
Time	(Carcasses/ Minute)	Volume (Liter/Minute)	Pressure Bar	(Yes/No)	(Yes/No)	(˚C)	(˚C)	(Liter/Minute)	(˚C)
Comments:									

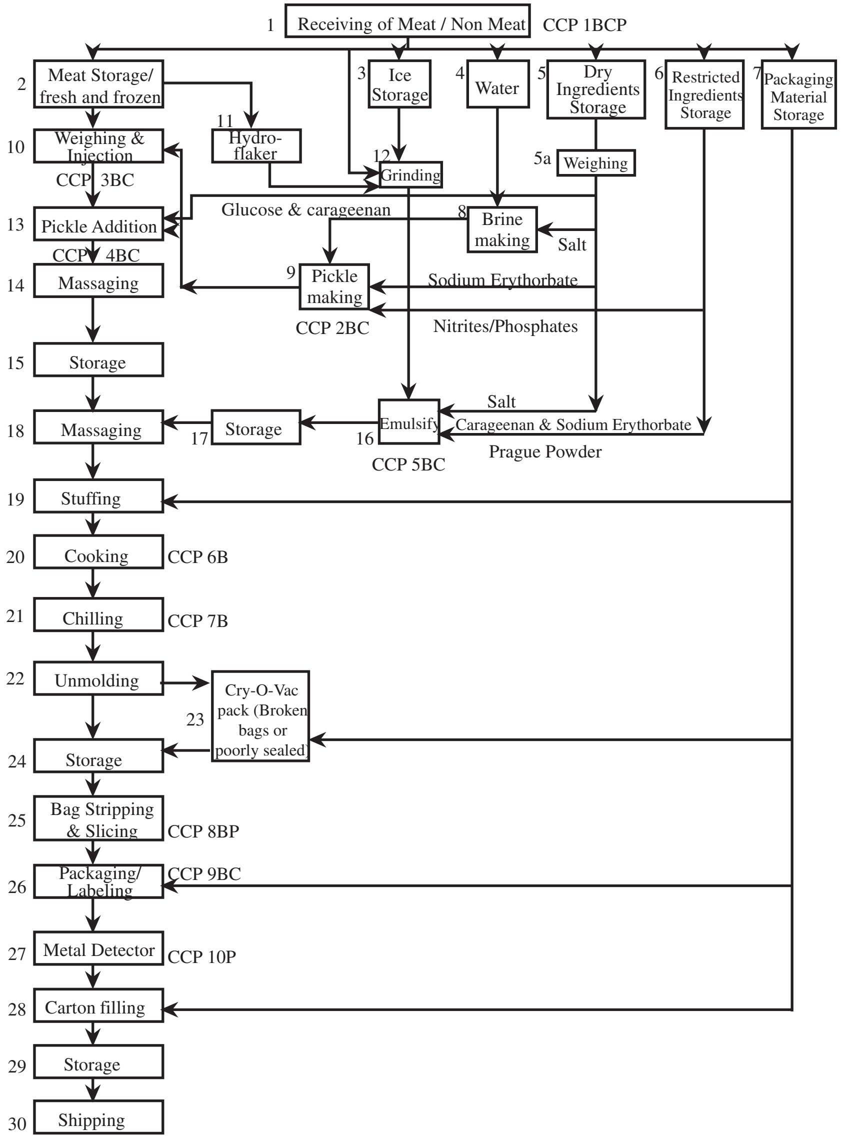

Figure 12.2. *Process Flow Diagram—Cooked, Sliced Turkey Ham, Including Suggested Critical Control Points (CCP). The Letter B Refers to a Biological Hazard; C = Chemical and P = Physical. From CFIA (1998b).*

Table 12.7. Biological (B), Chemical (C) and Physical (P) Hazards and Critical Control Points (CCP), Related to Ingredients, Incoming Raw Materials, Processing and Product Flow for Cooked, Sliced Turkey Ham. From CFIA (1998b).

Identified Biological Hazards (Bacteria, Parasites, Viruses, etc.)	Control Point(s)
Incoming Materials	
Raw turkey (as received) and ground turkey trim: non-spore-forming pathogenic bacteria—*Listeria monocytogenes, Staphylococcus aureus, Yersinia* sp., *Campylobacter* sp., *Salmonella* sp., *E. coli,* etc.; spore-forming pathogenic bacteria—*C. perfringens, C. botulinum,* etc.	CCP-6B CCP-7B
Water (as received): *coliforms,* fecal coliforms	Prerequisite programs (water quality program)
Ice (as received): *coliforms,* fecal coliforms	CCP-1BCP
Process Steps	
#1 Receiving of noncompliant material—fresh meat and non-meat ingredients: bacterial (pathogen) growth due to time/temperature abuse and cross contamination	CCP-1BCP
#2 Meat storage: bacterial growth due to time/temperature abuse	Prerequisite programs (transport and storage)
#7 Storage of packaging material: bacterial pathogens growth due to environment (rodent, insects, etc.)	Prerequisite programs (sanitation and pest control)
#9 Pickle making: bacterial pathogen growth in finished product due to insufficient amount of nitrite in pickle formulation	CCP-2BC
#10 Weighing and injection: bacterial pathogen growth in finished product due to too little pickle in product	CCP-3BC
#12 Grinding: contamination due to poor sanitizing of equipment	Prerequisite programs (sanitation)
#13 Pickle addition: bacterial pathogen growth due to insufficient amount of pickle	CCP-4BC
#15 Storage: bacterial pathogen growth due to time/temperature abuse	Prerequisite programs (transport and storage)
#16 Emulsification: bacterial pathogen growth in finished product due to insufficient addition of Prague powder	CCP-5BC

Table 12.7. (continued)

Identified Biological Hazards (Bacteria, Parasites, Viruses, etc.)	Control Point(s)
#16 Emulsification: bacterial pathogen growth due to time/temperature abuse	Prerequisite programs (employee training)
#17 Storage of emulsion: bacterial pathogen growth due to time/temperature abuse	Prerequisite programs (transport and storage)
#19 Stuffing: bacterial pathogen growth due to time/temperature abuse	Prerequisite programs (employee training)
#20 Cooking: survival of pathogens due to inadequate temperature or cooking time	CCP-6B
#21 Chilling: spores of *C. perfringens* sporulation and growth due to inadequate chilling rate	CCP-7B
#22 Unmolding: bacterial contamination from poor handling of bags	Prerequisite programs (employee training)
#23 Vacuum packing (broken, poorly sealed bags): cross contamination with pathogens (e.g., *Salmonella* sp., *L. monocytogenes, S. aureus,* etc.) by employee inadequate handling/unclean equipment	Prerequisite programs (employee training)
#24 Storage: bacterial pathogen growth due to time/temperature abuse	Prerequisite programs (transport and storage)
#25 Bag stripping and slicing: cross contamination with pathogens (e.g., *Salmonella* sp., *L. monocytogenes, S. aureus,* etc.) by employee inadequate handling/unclean equipment	CCP-8B
#26 Packaging/labeling cross contamination with pathogens (e.g., *Salmonella* sp., *L. monocytogenes, S. aureus,* etc.) by employee inadequate handling/unclean equipment	Prerequisite programs (employee training)
#26 Packaging/labeling: bacterial pathogen growth due to improper coding (best before)	CCP-9BC
#29 Storage: bacterial pathogen growth due to time/temperature abuse	Prerequisite programs (transportation and storage)
Identified Chemical Hazards	Control Point(s)
Incoming Materials	
Raw turkey (as received) and ground turkey trim: antibiotics, pesticides, drug residues	See Table 12.3

(continued)

Table 12.7. (continued)

Identified Chemical Hazards	Control Point(s)
Water (as received): chemical residues in incoming water	Prerequisite programs (water quality program)
Ice (as received): chemical residues in incoming ice	N/A
Packaging material (as received): chemical migration of non-food-grade packaging material, inaccurate labeling by supplier	CCP-1BCP
Process Steps	
#1 Receiving: receiving of noncompliant material (see above)	CCP-1BCP
#9 Pickle making: excess nitrite in the pickle	CCP-2BC
#10 Weighing and injection: excess nitrite in the pickled product (overpumping)	CCP-3BC
#13 Pickle addition: toxicity—excess of nitrite (over addition)	CCP-4BC
#16 Emulsify: excess nitrite added as Prague powder	CCP-5BC
#26 Packaging/labeling: (some ingredients not declared on label; allergic reactions due to wrongly labeled product)	CCP-9BC
Identified Physical Hazards	Control Point(s)
Incoming Materials	
Foreign material of nonmetallic origin in meat	CCP-1BCP
Foreign material of nonmetallic origin in ice	CCP-1BCP
Foreign material of nonmetallic origin in salt	N/A
Metallic particles in meat	CCP-10P
Metallic particles in ice	CCP-10P
Metallic particles in salt	N/A
Packaging material contamination with foreign material	CCP-1BCP
Process Steps	
#1 Receiving of meat and non-meat products: contamination with foreign material (see above)	CCP-10P
#5 Storage/weighing of dry ingredients: contamination with foreign material	Prerequisite programs (transport and storage)

Table 12.7. (continued)

Identified Physical Hazards	Control Point(s)
#6 Storage of restricted ingredients: contamination with foreign material	Prerequisite programs (transport and storage)
#7 Storage of packaging material: contamination with wood, metal, etc.	Prerequisite programs (transport and storage)
#8 Brine making: foreign material falling into the brine	Prerequisite programs (premise control, equipment maintenance)
#9 Pickle making: foreign material falling into the pickle solution	Prerequisite programs (premise control, equipment maintenance)
#10 Weighing and injection: broken needles	CCP-10P
#11 Hydroflaking: metal fragments from damaged inadequately maintained equipment	Prerequisite programs CCP-10P
#12 Grinding: nonmetallic foreign material	Prerequisite programs (premise control, equipment maintenance)
#12 Grinding: metal fragments from damaged, inadequately maintained equipment	Prerequisite programs (equipment maintenance) CCP-10P
#14 Massage: metal fragments from damaged, inadequately maintained equipment	Prerequisite programs (equipment maintenance) CCP-10P
#15 Storage: foreign material falling in product	Prerequisite programs (premise control, equipment maintenance)
#16 Emulsify: metal fragments from damaged, inadequately maintained equipment	Prerequisite programs (equipment maintenance) CCP-10P
#18 Massaging: metal fragments from damaged, inadequately maintained equipment	Prerequisite programs (equipment maintenance) CCP-10P
#19 Stuffing: metal fragments from damaged, inadequately maintained equipment	Prerequisite programs (equipment maintenance) CCP-10P

(continued)

Table 12.7. (continued)

Identified Hazards	The Way the Hazard could be Addressed (Cooking Instructions, Public Education, Use Before Date, etc.)
Incoming Materials	
#19 Stuffing: nonmetal foreign material contamination	Prerequisite programs (premise control, equipment maintenance)
#27 Metal detector: malfunction of the metal detector—ferrous metal and aluminum not properly detected	CCP-10P
Chemical: antibiotics, drug residues, pesticides in incoming meat products	Producer education and practices/proper withdrawal periods observed

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concern is the introduction of pathogens to the cooked product prior to packaging. Because the cooking process is designed to kill all/most of the non-spore forming bacteria such as *listeria,* post-cooking contamination can become a major problem to the manufacturer (e.g., see discussion on *listeria* in Chapter 11).

Chemical hazards may include antibiotics, pesticides and other drug residues that are obviously not permitted in the product.

Physical hazards may include metallic and nonmetallic substances (e.g., glass, wood) that might accidentally be incorporated in the product. The processing steps should be designed to eliminate such particles, and monitoring equipment, such as metal detectors, should be installed to identify and remove any ferrous-containing particles (see also Figure 8.17).

Table 12.8 shows a detailed step-by-step design of an HACCP plan to control the different hazards.

Table 12.9 illustrates an example of a HACCP record-keeping sheet for monitoring the showering and chilling of the final cooked product. It is essential that the process be monitored on a continuous basis. Any problem will be flagged as soon as possible, and predetermined corrective action(s) and/or reprocessing will be understood and followed by the employees involved in the process.

BATTERED AND BREADED CHICKEN FILLETS—A GENERIC HACCP MODEL

This model describes an uncooked, breaded poultry product that represents a range of par-fried poultry products (see also Chapter 10 for procedures and

Table 12.8. An Example of a Suggested HACCP Plan for Cooked, Sliced Turkey Ham. From CFIA (1998b).

Process Steps	CCP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#1 Receiving	CCP-1BC	Presence of pathogenic bacteria; bacterial pathogen growth due to time/temperature abuse and cross contamination	Normal color and odor; contractual specifications for meat products; maximum temperature of 4˚C at the center and surface of meat products; Slaughter/ packaging date (maximum "X" days) for fresh meat; contractual specifications (hygienic slaughter and boning/handling procedures + transport temperatures for meat products)	Receiver to check lots covered by contractual specificatons for each product lot received; receiver to take-temperature of every lot of meat; check slaughter packaging date; visually, examine for carton damage; organoleptic examination of product	Receiver is to place noncompliant shipment on hold and inform foreperson and supplier; product is to be returned or QC test/decision	QC to verify log book and procedures once a week; QC check temperature and collect sample for micro-verification once a week; QC to audit supplier plants	Receiver's log, book; QC records; temperature book; microlab analysis records
		Bone chips in boneless turkey; extraneous material including metal, wood	No foreign material 2 mm or larger	Receiver checks that contractual specifications exist for incoming material; boneless turkey inspection program at supplier level; receiver checks product if cartons are damaged	Hold shipment and inform foreperson and supplier	QC to verify log book once per week; QC to perform boneless reinspection every "X" shipment; product random sample	

(continued)

Table 12.8. (continued)

Process Steps	CCP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
		Packaging material non-food grade	Contractual specifications—“approved” material only	Receiver to allow unloading only if from approved supplier/material	Do not allow unloading; notify QC; QC holds products, requests proof of approval or returns product		
#9 Pickle making	CCP-2BC	Too little/too much sodium nitrite ($NaNO_2$) in the pickle mixture	“Y” ppm for each formulation (volumetric measuring devices within laboratory tolerances)	Inventory control sheet by pickle maker; daily check for each recipe; test strips used by pickle maker on each batch to indicate presence of nitrite	Pickle maker to notify foreperson, hold pickle; foreperson to hold product already pumped and notify QC	QC to test pickle batches 2×/week with test strips; review of records 1×/week	Pickle room check sheet; lab reports
#10 Weighing and injection	CCP-3BC	Too little $NaNO_2$ in the product; excess of $NaNO_2$ in the pickled product (overpump)	Weight after pumping equals weight before pumping plus “X”%	Operator records green and pumped weight on control sheet and ensures that % of pumping is respected	Recalibrates injection machine, holds product; informs QC of overpumped product	Foreman audits control sheets 2×/day and verifies % of pumping; QC verifies control sheet weekly (green weight vs. pumped weight) and verifies % of pumping	Injection control records; control sheet

Table 12.8. (continued)

Process Steps	CCP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#13 Pickle addition	CCP-4BC	Underpump, too little $NaNO_2$ in the product; excess of $NaNO_2$/overpump	Pump at "X"%	Batch weight to equal green weight + "X"%; finished weight to equals formula weight for each batch	Add more pickle, standard operating procedure is to purposely underpump; pickle injector operator is responsible for topping each batch to the correct weight, adjust pickle injector	Control sheet; daily scale checks with check weights; foreperson audits control sheets 2×/day; QC verifies control sheets weekly (green weight vs. pumped weight)	Control sheet; scale check sheet
#16 Emulsify	CCP-5BC	Too little or excess of $NaNO_2$ in the emulsion	Add correct weight of Prague powder as per formula	Batch control sheets; formulation signed by the operator	Hold, contact foreperson and QC; QC to reformulate	Random lab analysis performed by QC 2× per week; foreperson to verify 1×/day	Batch control sheets; QC lab report
#20 Cooking	CCP-6B	Survival of pathogens due to inadequate cooking time or temperature	Cooking house temperature/time cycle functioning; temperature and time limits "X" hours and "Y"°C.	Check cooking cycle; manual temperature check by the operator for every batch; thermograph checked and signed by the operator	Cook to internal temperature of "Y"°C (extend cooking time as necessary)	Thermograph charts reviewed weekly by QC	Thermograph charts kept on file by QC
#21 Chilling	CCP-7B	Growth of *C. perfringens*	Chill to 4°C in 12 hours or less; chill water temperature cycle as defined in plant chilling process	Every batch has a manual temperature check by the operator; shower product to "Y"°C internal temperature, chill to	Operator monitors room temperature and records deviations; temperature control person investigates if there is a deviation	Records reviewed by QC on a daily basis; audit monitoring procedures at "X" frequency	Room temperature records and product internal temperature

(continued)

Table 12.8. (continued)

Process Steps	CCP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
				4°C in 12 hours or less; check chill water temperature	and if problem cannot be corrected within 1 hour, he/she contacts foreperson in charge of production; product moved to coldest section for chilling		
#25 Bag stripping and slicing	CCP-8B	Cross contamination of product or improper employee handling practices	Clean and sanitized gloves; contact with anything other than the loaves requires hand dipping (sanitizing) prior to resuming bag stripping duties; no tolerance of soiled gloves or hands	Monitoring by foreperson of employee practices by random inspection 2×/day and recording results	Foreperson will instruct the employee on proper procedure and monitor until the employee's performance is satisfactory; product trimmed, sent for rework	QC to verify employee handling practices through periodic audits 1×/week; QC swabs gloves and contact surfaces at least once a week	Departmental QC check sheets; swab reports on equipment and gloves
#26 Packaging	CCP-9BC	Pathogenic bacterial growth due to wrong best before date	Correct date as determined by shelf life testing	Designated employee checks best before date when checking ingredients listing for each lot	Foreperson detains defective packages for repackaging; record each incident	QC verifies best before date and ingredients listing vs. formulation records "X" times/month	Departmental QC check sheets
		Allergies due to incomplete/wrong list of ingredients for the product	Label to match the product; no tolerance	Line operator (label installer) will check to ensure correct label is in place at start of each lot and record results	Designated employee will hold product for repackaging/relabeling correctly	Foreperson to randomly check 2×/day and record beginning of each product run; QC reviews departmental check sheet weekly	Departmental QC check sheets

Table 12.8. (continued)

Process Steps	CCP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#27 Metal detector	CCP-10P	Metal and aluminum not detected due to detector not functioning or improper calibration	No metal greater than 2 mm in size	Every package goes through the metal detector; electrician checks the calibration of the metal detector prior to the start of operations each day and signs the check sheet; employee checks function of detector by running a test wand through the metal detector 4× per day	If larger than 2 mm in size, product is rejected by the metal detector; notify foreperson and QC; every "ringer" the lot goes to QC for investigation; product is held until QC determines cause; product is retested since last satisfactory test	QC runs test wand through the metal detector 4× per week; every "ringer" goes to QC for investigation	Departmental daily check sheet; lab contamination report from QC; contamination file

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Table 12.9. An Example of a HACCP Record-Keeping Sheet—Shower Chill of Cooked, Sliced Turkey Ham. From CFIA (1998b).

Freq.	Foreman	Each Batch	Each Batch	Each Each Batch	Each Batch	Each Batch	Each Batch	Each Batch	Each Batch		
	Q.C.	Freq. “X”	Freq. “X”	Freq. “X”	Freq. “X”	Freq. “X”	Freq. “X”	Freq. “X”	Freq. “X”		
Date	Hour	LOT#	Start shower time	End shower time	Temperature of product “Y”˚C	Chill time in	Chill time out	Final product chill temp. max 4˚C	Total chill time (from start of shower to final chill) max 12 hours	Results/Actions	Initials

recipes). It is important that the microbial load be controlled when the raw ingredients are received, and that later, the meat be properly handled during the coating operation. In most cases, the product is distributed frozen, where proper labeling (i.e., keep frozen) should clearly appear on the package. In addition, instructions for adequate cooking (time and temperature), at the consumer level, are critical to ensure pathogen destruction because the product is not fully cooked when purchased by the consumer. Some fried, breaded poultry products are fully cooked by the processor where a HACCP model referring to a fully cooked product, should be used.

The general product description includes the following:

- product name—seasoned, battered and breaded chicken breast fillets
- important product characteristics—par-fried (i.e., 30–60 seconds frying), individually quick-frozen (IQF) product; no preservatives or low pH which will inhibit bacterial growth
- product use—frozen before cooking; must be fully cooked to an internal temperature of at least 72°C
- packaging—shipping carton packaged in bulk plastic liner/sealed with tamper-evident tape
- shelf life—a year if kept at −18°C or below
- distribution—food service and retail
- labeling instructions—lot number, keep frozen, cooking instructions, ingredient list
- special distribution control—use refrigerated truck at −18°C or colder

The meat ingredients include chicken meat and non-meat ingredients such as salt, spices, sugar, gums, soy proteins, wheat crumbs, wheat flour, corn flour, starch, vegetable oil and water.

Figure 12.3 shows the flow diagram of the process and suggested critical control points (CCP.

Table 12.10 lists the biological, chemical and physical hazards that might cause problems with the product. The list begins with incoming raw materials (meat, water, different dry ingredients such as flours, sugar and spices), which might harbor bacteria (biological hazards), include some antibiotic/pesticide residues (chemical hazards) or might contain particles such as metal or bone chips (physical hazards). These hazards should mainly be addressed by the CCP-1, where the raw ingredients should be inspected prior to accepting them into the plant. In addition, CCP-4, which refers to the use of a metal detector, is also included in order to minimize the risk of metal particles (e.g., nails/needles that found their way into the muscle during the growing period, bolts that have fallen off processing equipment) present in the final product.

Table 12.11 shows a systematic approach to developing critical limits, monitoring procedures, deviation procedures, verification procedures and record keeping as outlined in the seven HACCP principles discussed at the

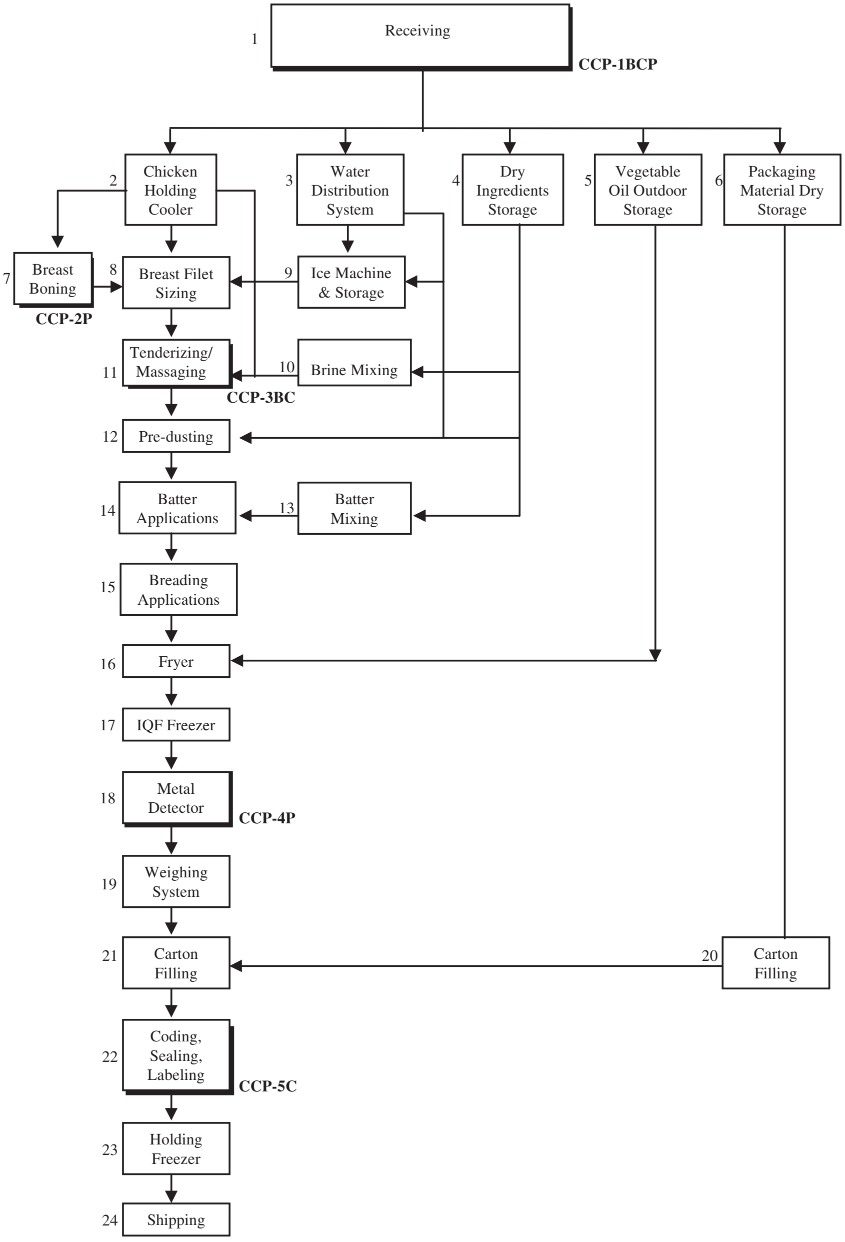


Figure 12.3. *Process Flow Diagram—Chicken Breast Fillets Including Suggested Critical Control Points (CCP). From CFIA (1998c).*

Table 12.10. Biological (B), Chemical (C) and Physical (P) Hazards and Critical Control Points (CCP) Related to Ingredients, Incoming Material, Processing and Product Flow for Ready-to-Cook Breaded Chicken Breast Fillets. From CFIA (1998c).

Identified Biological Hazards, (Bacteria, Parasites, Viruses, etc.)	Control Point(s)
Incoming Materials	
Chicken breasts and breast fillets: contamination with pathogenic bacteria (e.g., *Salmonella* sp., *Campylobacter* sp.,*Staphylococcus aureus, Yersinia enterocolitica, Listeria monocytogenes*, *Escherichia coli* and *Clostridium perfringens*)	CCP-1BCP
Water: water not meeting the drinking water criteria established by the government	Prerequisite programs (water quality)
Wheat, flour, corn flour, toasted wheat crumbs and starch: presence of mycotoxins, high aerobic spore count, grain beetles	CCP-1BCP
Sugar, glucose solids, dextrose: contamination at source with pathogenic bacteria (e.g., *Clostridium perfringens* and *Bacillus cereus, Listeria monocytogenes, Salmonella,* sp.)	CCP-1BCP
Spices: contamination at source with pathogenic bacteria or spores (e.g., *Clostridium perfringens* and *Bacillus cereus, Salmonella* sp., *E. coli)*, presence of mycotoxins	CCP-1BCP
Process Steps	
#1 Reception of noncompliant material: see "Incoming Materials" (above)	CCP-1BCP
#2 Holding cooler: pathogenic bacterial growth due to excess time (improper stock rotation) or inadequate refrigeration	Prerequisite programs (storage)
#3 Water distribution system: pathogenic bacterial contamination and growth within water pipes due to back-siphonage of contaminated water or "dead-ends"	Prerequisite program (water quality and maintenance)
#4 Dry ingredients storage: pathogenic bacterial contamination from rodents, insects or improper handling (damaged containers with contamination of exposed product.)	Prerequisite program (pest control and employee training)
#7 Breast boning and sizing: pathogenic bacterial contamination due to improper handling procedures	Prerequisite program (employee training)

(continued)

Table 12.10. (continued)

Identified Biological Hazards, (Bacteria, Parasites, Viruses, etc.)	Control Point(s)
#8 Breast fillet sizing: pathogenic bacterial contamination due to improper handling procedures	Prerequisite program (employee training)
#9 Ice machine and storage: pathogenic bacterial contamination due to inadequate cleaning and sanitizing of equipment.	Prerequisite program (sanitation)
#10 Brine mixing: pathogenic bacterial contamination due to improper employee hygiene, work habits and equipment operating practices.	Prerequisite program (employee training)
#11 Tenderizing/massaging: pathogenic bacterial contamination due to improper handling and growth due to time/temperature abuse or inadequate cleaning of equipment	CCP-3BC
#12 Pre-dusting: pathogenic bacterial contamination due to improper employee hygiene, work habits and equipment operating practices.	Prerequisite program (employee training)
#13 Batter mixer: pathogenic bacterial contamination due to improper employee hygiene, work habits and equipment operating practices.	Prerequisite program (employee training)
#14 Batter application: pathogenic bacterial contamidnation due to improper employee hygiene, work habits and equipment operating practices (time/temperature control)	Prerequisite program (employee training)
#15 Breading application: pathogenic bacterial contamination due to improper employee hygiene, work habits and equipment operating practices	Prerequisite program (employee training)
#17 I.Q.F. freezer: pathogenic bacterial growth due to failure to adequately freeze the product	Prerequisite program (storage)
#19 Weighing system: pathogenic bacterial contamination due to improper employee hygiene, work habits and equipment operating practices	Prerequisite program (employee training)
#20 Carton assembly (and plastic liner insertion): pathogenic bacterial contamination (e.g., *Salmonella* sp.) associated with dust contamination of product contact surfaces of inserted and opened liners	Prerequisite program (employee training)
#21 Carton filling: pathogenic bacterial contamination due to improper employee hygiene, work habits and equipment operating practices.	Prerequisite program (employee training)
#22 Coding, sealing and labeling: pathogenic bacterial contamination due to improperly sealed bags or cartons (exposed product)	Prerequisite program (employee training)

Table 12.10. (continued)

Identified Biological Hazards, (Bacteria, Parasites, Viruses, etc.)	Control Point(s)
#23 Holding freezer: contamination due to damaged cartons and pathogenic bacterial growth due to inadequate temperature	Prerequisite program (storage)
#24 Shipping: pathogenic bacterial contamination due to damaged cartons and growth due to time/temperature abuse	Prerequisite program (transportation)
Identified Chemical Hazards	Control Point(s)
Incoming Materials	
Chicken breasts and breast fillets: antibiotics, sulfonamide residues, pesticides, heavy metals	See Table 12.3
Water: toxic chemicals, e.g., heavy metals	Prerequisite program (water quality)
Wheat flour, corn flour, toasted wheat crumbs and starch: pesticide residues, allergens	CCP-1BCP
Spices: fumigant and pesticide residues, allergens	CCP-1BCP
Vegetable oil: pesticide residues, allergens	CCP-1BCP
Plastic bags and liners: chemical migration from non-food-grade ingredients	CCP-1BCP
Process Steps	
#1 Reception of noncompliant material: see “Incoming Materials” (above)	Prerequisite program (sanitation)
#7 Breast boning and sizing: chemical residue due to improper sanitation procedures (poor drainage of equipment, product contact surfaces)	Prerequisite program (sanitation)
#8 Breast fillet sizing: chemical residue due to improper sanitation procedures (poor drainage of equipment, product contact surfaces)	Prerequisite program (sanitation)
#10 Brine mixing: chemical residue due to improper sanitation procedures (poor drainage of equipment, product contact surfaces)	Prerequisite program (sanitation)
#11 Tenderizing/massaging: chemical residue due to improper sanitation procedures (poor drainage of equipment, product contact surfaces)	Prerequisite program (sanitation)

(continued)

Table 12.10. (continued)

Identified Chemical Hazards	Control Point(s)
#11 Tenderizing/massaging: allergens due to incorrect ingredients or formulation	CCP-3BC
#13 Batter mixer: chemical residue due to improper sanitation procedures (poor drainage of equipment, product contact surfaces)	Prerequisite program (sanitation)
#22 Coding, sealing and labeling: allergic reactions due to incorrect list of ingredients (wrong label)	CCP-5C
Identified Physical Hazards	Control Point(s)
Incoming Materials	
Metallic particles:	
Chicken breasts and breast fillets: e.g., knife chips metal chips and pieces from equipment	CCP-4P
Breading, batters, pre-dusts, salt and spices: metal chips and pieces from grinders	CCP-4P
Nonmetallic particles:	
Chicken breast fillets: bone and plastic particles	CCP-1BCP
Breading, batters, pre-dust and salt: hazardous extraneous material	CCP-1BCP
Spices: wood slivers	CCP-1BCP
Process Steps	
#1 Reception of noncompliant material: see “Incoming Materials” (above)	CCP-1BCP
#6 Packaging material storage: nails from skids (pallets), metal devices from packaging (staples) and other environmental contaminants due to-improper handling, e.g., exposed packaging material contaminated due to open or damaged cartons	Prerequisite programs (receiving/storage and employee training)
#7 Breast boning: bone particles and plastic particles from cones or cutting boards	CCP-2P
#7 Boning: metal chips from knives, mesh glove links, etc.	CCP-4P
#8 Breast fillet sizing: metal chips from knives, mesh glove links, etc.	CCP-4P

Table 12.10. (continued)

Identified Physical Hazards	Control Point(s)
#9 Ice machine and storage: metal chips and pieces due to metal fatigue and improper maintenance	CCP-4P
#10 Brine mixing: mixer blade chips due to metal fatigue, machine parts, e.g., screw, due to improper maintenance, and fragments from cracked scoops	Prerequisite programs (employee training)
#11 Massaging: metal chips and pieces due to metal fatigue or improper maintenance	CCP-4P
#12 Pre-dusting: cracked scoops and pieces of metal belt links and particles from ingredient containers	CCP-4P
#13 Batter mixer: mixer blade chips due to metal fatigue, machine parts, e.g., screw, due to improper maintenance and cracked scoops; particles from ingredient containers	CCP-4P
#14 Batter application: pieces of metal, belt links and machines parts, e.g., screws due to improper maintenance	CCP-4P
#15 Breading application: cracked scoops and pieces of metal belt links; particles from ingredient containers	CCP-4P
#16 Fryer: pieces of metal belt links	CCP-4P
#17 I.Q.F. freezer: pieces of metal belt links	CCP-4P
#18 Metal detector: failures to detect acceptable metallic fragment(s) due to improper calibration or malfunction	CCP-4P

Identified Hazards	The Way the Hazard could be Addressed (Cooking Instructions, Public Education, Use Before Date, etc.)
Incoming Materials	
Chemical: chicken breast and breast fillets: antibiotics, sulfonamide residues, pesticides, heavy metals	Growers' education; control at the farm level

Date: ____________ Approved by: ______________________________

Table 12.11. An Example of a Suggested HACCP Plan for Ready-to-Cook Breaded Chicken Breast Fillets. From CFIA (1998c).

Process Steps	CCP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#1 Receiving	CCP-1BC	Chicken meat (contamination with pathogenic bacteria)	Plant-specific contractual specifications, e.g., bacteria ("X" aerobic plate count or coliforms per ml, gr or sq. cm.), absence of specific bacterial pathogens, hygienic handling procedures during evisceration/boning, transportation temperature, maximum "X" days from slaughter/pack date; internal temperature less than or equal to 4°C when received; shipping containers clean and not damaged; no sign of spoilage on organoleptic inspection	For each lot, receiver to ensure that the contractual specifications are respected by the supplier; record and compare kill/pack date (age of product), temperature and container condition to specifications; one carton/pallet subjected to organoleptic inspection by receiver and observations and product temperature recorded	Receiver place noncompliant product on "hold"; inform supplier, QC and processing foreperson; product returned or QC test and proper disposition	QC to verify receiver's records "X" times/week; QC to verify product temperature and take sample for microtesting "X" time/month	Receiver's records; QC verification records; bacteria test results
		Chicken meat (bone and plastic particles)	Less than or equal to 2 mm for bone or plastic particles	Receiver perform boneless chicken reinspection for each shipment until "X" consecutive	QC notified; shipment placed on "hold" and either returned or reworked	QC to observe and verify records for boneless chicken reinspection "X" times/month	Receiver's reinspection records, QC verification records

Table 12.11.(continued)

Process Steps	CCP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
				lots passed, then select every "X"th shipment			
	CCP-1BPC	Spices and vegetable oil (pesticide, residues, mycotoxins and allergens and for spices, fumigant residues); Chicken meat (antibiotic, sulphonamide and coccidiostat residues)	Government Standards	For each lot received, receiver ensure signed contract with supplier on file and record same; contract to include plant-specific specifications and compliance with Health Canada standards, e.g., extraneous material less than 2 mm and freedom from allergens as applicable	Receiver place non-compliant product on "hold" and inform QC, supplier and processing foreperson pending signed contract or refuse shipment	QC verify receivers records "X" times/ month	Receiver's records; QC verification records
		Spices and salt (hazardous extraneous material)	less than or equal to 2 mm	For each lot received, receiver ensure signed contract with supplier on file and record same; contract to include plant-specific specifica-	Receiver place non-compliant product on "hold" and inform QC, supplier and processing foreperson pending signed contract or refuse shipment	QC verify receivers records "X" times/ month	Receiver's records; QC verification records

(continued)

Table 12.11.(continued)

Process Steps	CCP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#1 Receiving (cont'd)	CCP-1BCP			tions and compliance with government standards, e.g., extraneous material less than 2 mm and freedom from allergens as applicable			
		Spices, sugar, glucose solids, dextrose (contamination with patho--genic bacteria)	Plant specific; contractual specifications	For each lot received, receiver ensure signed contract with supplier on file and record same; contract to include plant-specific specifications and compliance with government standards, e.g., extraneous material less than 2 mm and freedom from allergens as applicable	Receiver place noncompliant product on "hold" and inform QC, supplier and processing foreperson pending signed contract or refuse shipment	QC verify receiver's records "X" times/ month	Receiver's records; QC verification records

Table 12.11.(continued)

Process Steps	CCP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#1 Receiving (cont'd)	CCP-1BPC	Wheat flour, corn flour toasted wheat, crumbs and starch: (mycotoxin(s), pesticide residue and allergens)	Government standards	Signed contract specifying absence of mycotoxins and compliance with government standards	Receiver place non-compliant product on "hold" and inform QC, supplier and processing foreperson pending signed contract or refuse shipment	QC verify receiver's records "X" times/ month	Receiver's records; QC verification records
		Packaging material (non-food-grade material)	No packaging material not listed by the government to be received	For each lot received, receiver ensure packaging material is listed	Receiver place non-compliant product on "hold" and inform QC, supplier and processing foreperson pending signed contract or refuse shipment	QC verify receiver's records "X" times/ month	Receiver's records; QC verification records
#7 Boning and sizing	CCP-2P	Bone or plastic particles	Less than or equal to 2 mm	Designated employee perform boneless chicken reinspection on each lot after or during (on-line) boning	Notify QC and hold product; rework entire lot, then reinspect again; retrain employees	QC to verify reinspection procedure and records "X" times/ month	Reinspection records; QC verification records
#11 Massaging	CCP-3BC	Growth of pathogenic bacteria	Maximum "X" hour per cycle at "X"°C maximum	Designated employee record time and product temperature in/out and room temperature	Designated employee "holds" product and notifies QC; if deviation does not exceed "X"°C or "Y" time, then product can be redirected	QC verify records and product tags "X" times/month	Massage and QC verification records

(continued)

Table 12.11.(continued)

Process Steps	CCP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
					to cooked product; if it exceeds these limits, QC to decide on product disposition		
	CCP-3BC	Allergens	Correct ingredients as per recipe	Designated employee performs recipe ingredient check off/formulation records, completes and tags/ID product	QC hold product; relabel (correctly) product	QC verify records and product tags "X" times/month	Formulation records; QC verification records
#18 Metal detector	CCP-4P	Metal particles in meat product	Maximum 2 mm ferrous and nonferrous	Foreperson will check/recalibrate every "X" hours to ensure metal detector is working and record findings	Foreperson to notify QC and to hold the previous "X" hours production; repair detector; recheck held product for metal; product rejected by metal detector examined by foreperson and QC to establish probable cause and correct source of metal piece(s) if of processing plant origin or notify supplier if applicable	QC to verify records and test metal detector "X" times/week	QC records on metal detection audit; metal detector records

Table 12.11.(continued)

Process Steps	CCP/Hazard Number	Hazard Description	Critical Limits	Monitoring Procedures	Deviation Procedures	Verification Procedures	HACCP Records
#22 Coding sealing and labeling	CCP-5C	Allergic reactions due to incorrect list of ingredients	Correct label	Foreman to check every “X” hour to ensure correct code and label	Foreperson notify QC and hold product from last “X” hours production; 100% reinspection; correct condition	QC verify records “X” times/week and correlate label vs. formulation records	QC records on coding and labeling

Date: __________ Approved by: __________

beginning of the chapter. Limits for each control point should be established by plant personnel in conjunction with the appropriate inspection agency.

Table 12.12 provides an example of a record-keeping sheet for the metal detector (see Chapter 8 for operational principles) and carton operations. As indicated earlier, part of the verification process can be the inclusion of a marked sample containing metal particles to ensure that it is flagged by the metal detector. The information collected on the HACCP record-keeping sheets should be shared with all parties concerned, so effective and immediate corrective actions can be taken.

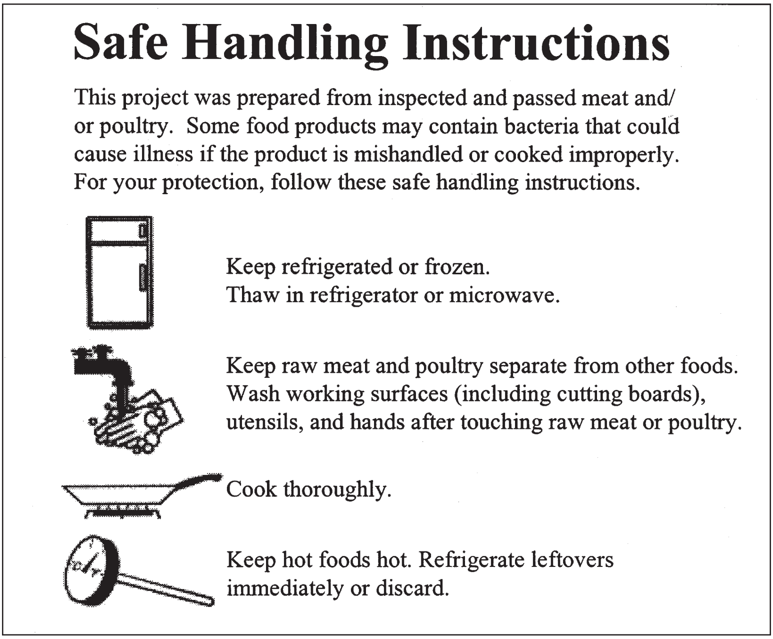
Figure 12.4 shows a safe handling label suggested by the American Meat Industry and the USDA. Such a label, which includes simple icons, is used to educate/remind the consumer to use common sense when handling perishable meat products.

Table 12.12. An Example of a HACCP Record-Keeping Sheet—Metal Detector and Cartons. From CFIA (1998c).

Time	Product Name	Good Carton Seal		Correct Code Date*		Correct Label*		Metal Detector Rejects Metal Test Samples	
		Yes	No	Yes	No	Yes	No	Yes	No

*Note: Attach a copy of label(s) with code date(s)

DATE: ____________________ APPROVED BY: ______________________________________



Safe Handling Instructions

This project was prepared from inspected and passed meat and/or poultry. Some food products may contain bacteria that could cause illness if the product is mishandled or cooked improperly. For your protection, follow these safe handling instructions.

Keep refrigerated or frozen.
Thaw in refrigerator or microwave.

Keep raw meat and poultry separate from other foods. Wash working surfaces (including cutting boards), utensils, and hands after touching raw meat or poultry.

Cook thoroughly.

Keep hot foods hot. Refrigerate leftovers immediately or discard.

Figure 12.4. *A Safe Food Handling Label. Proposed by the American Meat Industry and the United States Department of Agriculture.*

Overall, the benefits of a good HACCP plan, apart from enhancing food safety, include a faster response to production problems, better use of resources and continuous inspection of production, and a good plan assists in improving processing procedures.

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CHAPTER 13

Meat Color and Flavor

INTRODUCTION

COLOR plays an important role in our daily life. Humans spend a lot of time selecting and matching colors, including choosing the color of their dress, colors with which to decorate their homes, car colors and food colors. In the animal kingdom, color plays an important role in warning other species and attracting the opposite sex. For example, the peacock male shows off a magnificent presentation of colorful feathers, which actually requires a substantial investment of metabolic energy. For ducks, the production of vibrant colors and impressive feathers is used to attract the opposite sex and indicate the health of the bird. In the plant kingdom, colors are used in a variety of ways to attract insects and birds to pollinate flowers. Also, in this case, creating such colors requires a fair amount of energy from the plant's nutritional reserve, but it is important to sustain the specie.

Acceptance or rejection of food by humans is based, in part, on the color of the product compared to an expected reference. A simple sensory analysis test of a cooked scrambled egg mix can quickly illustrate this point. A green food coloring added to the mix will make the product unacceptable to most consumers, even though there are no flavor, textural or odor deviations from a normal yellow scrambled egg mix. If the product is presented under red light (i.e., commonly used in sensory analysis evaluations to eliminate color differences), the panelists will accept the scrambled egg mix without a problem. Humans also use color to provide some information regarding the flavor of a product. When the color of a product is switched to another color, people can be tricked into believing that the product has a different flavor. This is the case when researchers change the color of a strawberry sherbet from red to green, and various consumers assign a lemon flavor to the product. In poultry meat marketing, color is very important, and consumers are often willing to pay a premium for a product with an acceptable color. On the other hand, when consumers perceive a color problem/defect, they would probably not buy the product.

LIGHT AND COLOR

The colors we see are the result of light reflected from different objects. The light itself is a form of radiant energy usually produced by a hot object (e.g., sun, lightbulb, flashlight). The colors that we can see are a small part of the electromagnetic spectrum (see Figure 7.8 describing the spectrum). Overall, humans can see only a very small part of the whole spectrum (400–700 nm). Other animals, such as bees, can see some ultraviolet light (a region where some flowers show vibrant "colors" seen by bees). Light waves radiate in all directions from their originating source. The vibration occurs at right angles to the direction of travel (Figure 13.1). The high points of a light wave are called crests, and the low points are called troughs. The distance from crest to crest is called wavelength. The number of vibrations, or cycles, per second is called frequency. When the wavelength (λ) is multiplied by the frequency (ν), the result is the speed of light (c):

$$c = \lambda\nu$$

This relationship indicates that as wavelength goes up, frequency goes down, because the speed of light is constant in a vacuum environment. This can be used to explain why violet light ($\lambda = 400-425$ nm; $\nu = 75 \times 10^7$ cycles/second) is more penetrating and potentially damaging to your skin and causes more problems with meat fading (see later discussion in this chapter) than red light ($\lambda = 650-700$ nm; $\nu = 40 \times 10^7$ cycles/second).

The white sunlight that we see can be split into its major components by using a prism (Figure 13.2). The glass prism shown in the figure splits the light since the "refractive index" is different for different wavelengths. This is the same phenomena seen in a rainbow when sunlight is split into its components by water droplets (rain) and is projected onto a screen (clouds). It should be mentioned that not all we perceive as white light is actually a true balanced composite of all the wavelengths (i.e., true sunlight). In the case of fluorescent light illumination, the human eye can quickly adjust and make it feel that we are exposed to a full-spectrum light source, even though some key components, such as red, are present in a small quantity. This topic and its effect on meat color will be discussed later in the chapter.

The color of an object the human eye sees is the result of the reflected light coming back from the object (Figure 13.3). In this example, a slice of dark turkey thigh meat is shown to absorb all/most of the blue and green light and reflect small amounts of yellow, moderate amounts of orange and a large amount of red light. Therefore, the overall color appears to be red. If a particular light source is missing a certain component of the spectrum (e.g., fluorescent lights are generally low on red), this color will not be clearly seen even if this wavelength can be reflected from the surface.

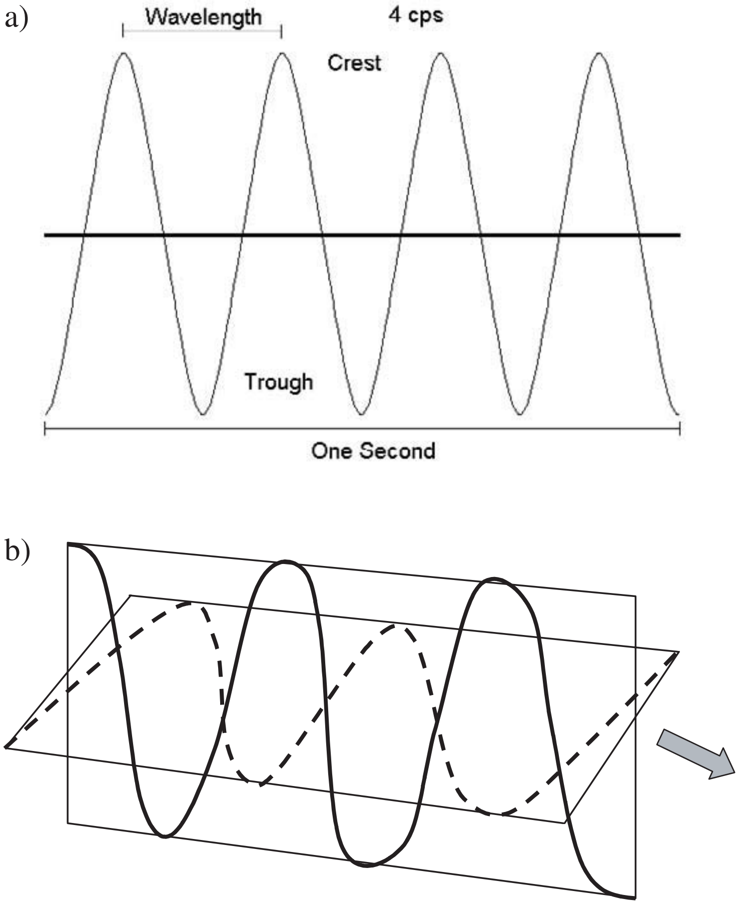

Figure 13.1. Wavelength is the Distance from One Crest to the Next, and Frequency is the Number of Wavelengths per Second as Shown in (a). Section (b) Shows that Light is a Three-Dimensional Electromagnetic Wave Vibrating at Right Angles to its Direction of Travel.

In the food industry, color measurements are used as an important quality control. Producing a consistent yellow margarine color is very important to the dairy industry and, producing a red ketchup color is essential in marketing the product. In the case of poultry, producing a chicken with a consistent skin color is very important to consumers who have certain expectations for a wholesome product. In certain parts of the world, light-colored chicken skin (almost white) is desired, whereas in other parts, a yellow skin color is praised. The farmer can modify the skin (and egg yolk) color by feeding the birds ingredients such as cornmeal, which contains carotenoids. The color can also be enhanced by adding synthetic xanthophylls to poultry feed.

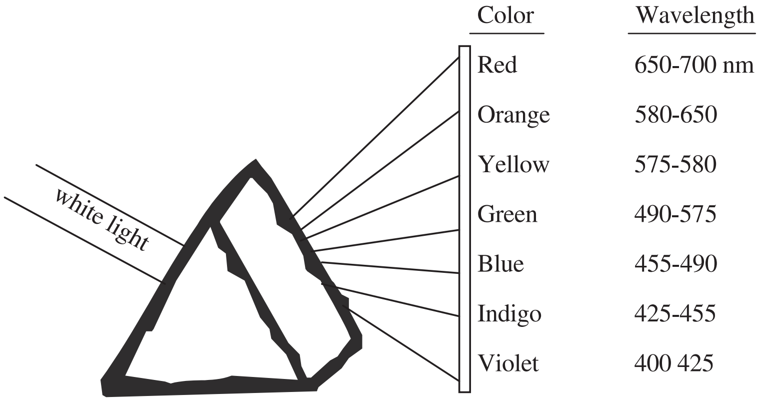

Figure 13.2. *Use of a Prism to Separate the White Sunlight into Its Components. Note that By Using a Second Prism, One can Combine the Colors to Reproduce the White Light.*

Measuring color and expressing it in a simple way is not as easy as one might think. In our daily lives, most people use descriptive terms to describe a specific color. An example would be the different descriptions that could be attached to the color green, ranging from dark to light and including grass green, hunter green, dull green, bright green, etc. The Gage Canadian Dictionary definition of color is “the sensation produced by the different effects of waves of light striking the retina of the eye. Different colors are produced by rays of light having different wavelengths.”

From a scientific point of view, color has to be expressed in a more precise way that would also allow its exact reconstruction. Therefore, when discussing color, the three components that should be included are the illumination source, the surface and the observer (human) or detector (instrument).

Fletcher (1999a) has provided a historical review of the different methods used by the poultry industry to measure and express color. Overall, the methods were divided into visual, chemical-spectral photometric (including direct pigment analyses) and reflectance colorimetry. Today, the most common method is reflectance colorimetry, but it is interesting to review the “evolution” of color measuring and description used by the poultry industry.

Visual description was introduced in the early 1900s when color chip standards were developed to score color of poultry skin and of egg yolk. Originally, a series of color standards was developed, assigned numbers and expressed on a fairly linear scale. One of the most successful ones was the Hoffman-LaRoche yolk color fan, which was also used for broiler skin color analyses. The color fan has been used for many decades and is still used today in certain parts of the world. It has been used to apply a subjective scoring to evaluate the skin color as affected by xanthophyll level in different

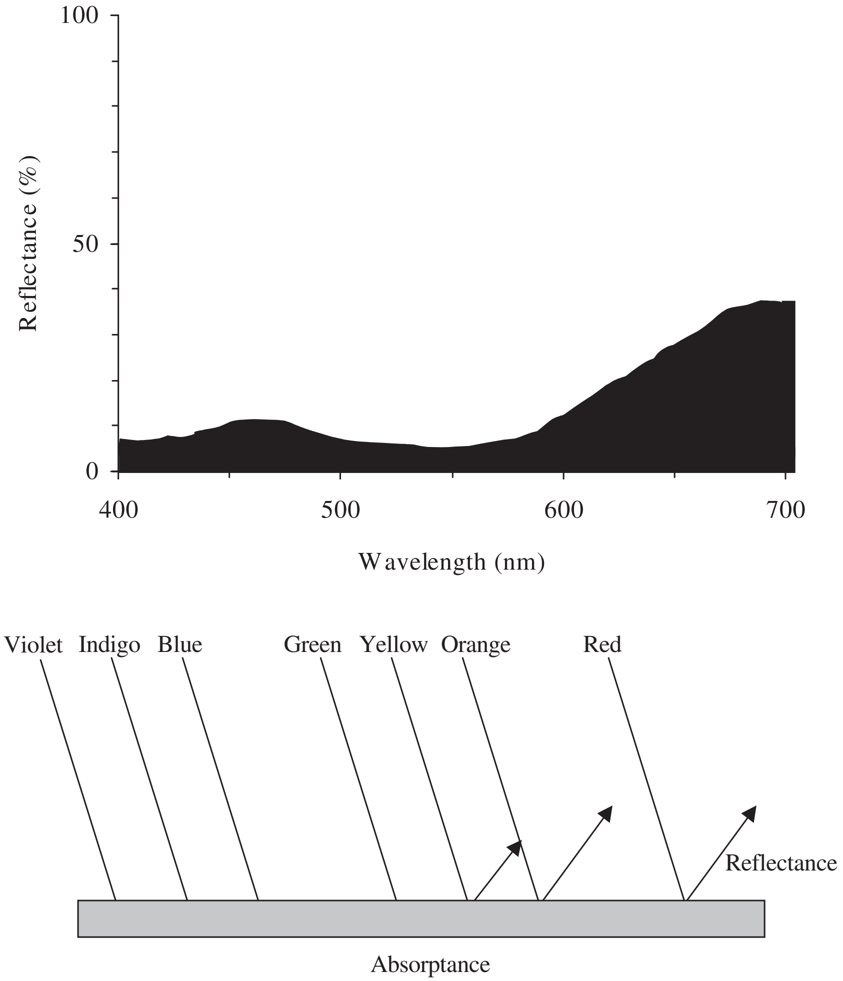

Figure 13.3. *Spectral Reflectance for Chicken Thigh Meat.*

diets, and it also served as a quality control measurement employed by some of the large commercial producers. Similar visual standards have been used by the red meat industry; currently, there is still a popular pork color scale that is used in various abattoirs to evaluate pork meat quality (e.g., presence and degree of PSE). Such a color chart system is not commonly used for evaluating poultry meat quality.

The chemical-spectral photometric methods are based on chemical extraction of different meat pigments and their quantification. The pigment can range from the yellow carotenoids found in feed material and deposited in the skin to the red heme pigment found in the blood and muscles. For skin color, some of the procedures include the extraction of pigments from a predetermined area of the shank (by acetone), followed by colorimeter evaluation. Muscle pigments, including heme and cytochrome C (i.e., suspected contributor to the pinkness of white cooked breast meat) have been extracted and quantified. Some of the problems encountered with the visual and chemical methods were due to the fact that the results, which were assumed to be linearly related to the final product's color, are usually not directly related. For example, the Hoffman-LaRoche color fan employs a linear scale to describe nonlinear color values. The problem is seen when skin color (or egg yolk color) values do not respond in a linear fashion to linear increments in carotenoids fed in the diet. The problem can also be seen when examining the relationship between the heme pigment content and meat color, because, often, the color is more affected by the chemical state of the heme pigment than its concentration in the tissue (Fletcher, 1999a).

Reflectance colorimetry is the most popular method used today in researching poultry meat color. It can overcome some of the problems mentioned earlier and eliminate the inherent problem of differences among observers (i.e., differences in color sensitivity among humans) when using a visual scoring system. It also eliminates problems with light source differences, background differences and light angle differences. The major advantages of reflectance colorimetry are its accuracy, objectivity and reproducibility. Some of the drawbacks are the dependence on more expensive equipment, potential operating errors and improper use.

A brief review of the concepts behind reflectance color measurement is provided below. Overall, three major terms are commonly used to describe our perception of color. The first is hue, which describes a primary color such as red, green or blue. The second is lightness or luminosity, which describes the lightness of the color. The third term is saturation, which describes how vivid or dull the color is. An example to illustrate the relationship between the three terms can be seen while slowly mixing blue paint into dull white paint. The color will gradually change from pale blue to dark blue, but the hue (blue in this case) remains unchanged. What changes is the saturation as the color progressively changes from dull white to vivid blue. The lightness or luminosity can be changed by using bright white paint instead of dull white, so the paint would be brighter (Swatland, 1989). A graphic description of hue, lightness and saturation is provided in Figure 13.4. In the illustration provided above, mixing more blue color is moving along the saturation axis toward the outside of the sphere. Using a brighter white paint as the starting ingredient is moving upwards along the lightness axis.

Over the years, different numerical systems have been developed. The CIE (Commission Internationale de l'Eclairage) in 1931 incorporated the spectral aspect of illuminating with three different colors into the so-called tristimulus values known as the *X, Y, Z*. The CIE *X, Y, Z* system defines a color by the

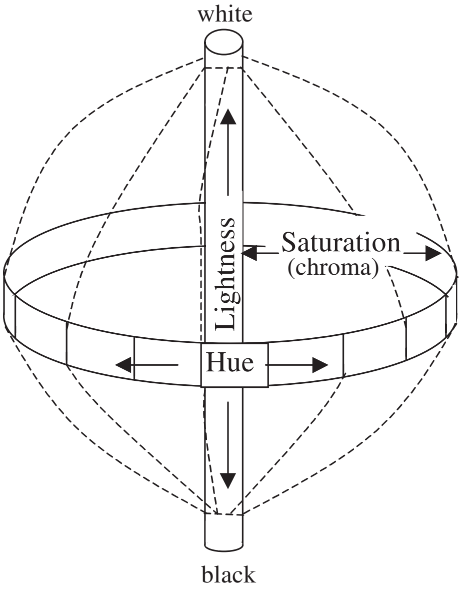

Figure 13.4. *The Relationship between Hue, Lightness and Saturation Presented in a Three-Dimensional Space. Derived from the Tristimulus Values of the CIE (1976). Note: in the CIE, Saturation is Termed Chroma.*

additive mixture of three primary colors, *X* (red), *Y* (green) and *Z* (blue), parameters that are required to match the color of a mixture as viewed by the "standard observer" (human) under defined illumination and viewing conditions. The concept of the tristimulus is based on the theory that the human eye possesses receptors for the three primary colors (red, green and blue), and that all other colors are seen as a mixture of the three. The system is useful to define colors, but the results are not easily visualized. Because of this, the CIE also defined other color spaces. One of the most popular systems is the so-called CIE LAB. It was defined by the CIE (1976) in order to minimize the problem that equal distances, on the chromaticity diagram, did not correspond to equal perceived color differences. The CIE LAB color space system is one of the most popular used by the meat industry. Another frequently used method for food applications is the Hunter *L, a, b* solids scale. The relationship between the CIE and other color scales has been discussed by Hunter (1975), Anonymous (1989) and Acton and Dawson (1994). The CIE LAB color space system is illustrated in Figure 13.5. The figure shows that the *L** value is an expression of the lightness of the surface ranging from 0 (black) to 100 (white). A positive *a** value indicates red with a higher value denoting more red. A negative *a** value indicates green. The positive and negative *b** values indicate yellow and blue, respectively.

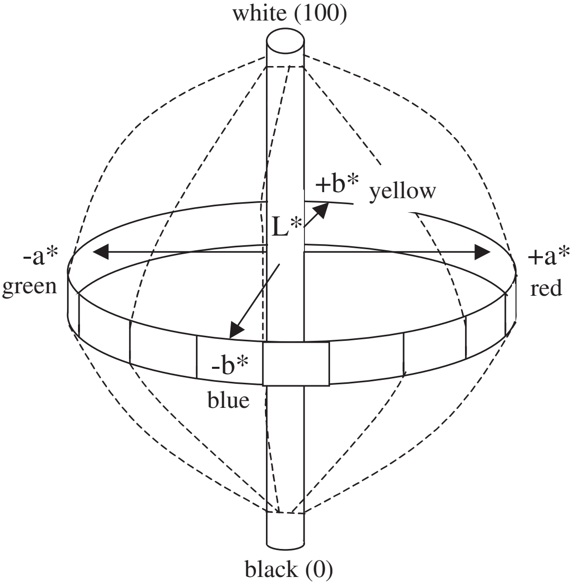

Figure 13.5. *Schematic Diagram of the CIE (1976) LAB Color Space System Used to Describe Colors. Each Color can be Expressed by Three Numbers Indicating Its Position in a Three-Dimensional Spherical Space. The Vertical Axis Shows Lightness to Darkness in a 0 (Black) to 100 (White) Scale. The a* Represents Redness (+a*) to Greenness (−a*) and the b* Shows Yellowness (+b*) to Blueness (−b*). Note: the Circle Shown in a Midway Position can be Moved Up or Down Depending on Lightness.*

MEAT COLOR

The red/brown meat color of meat is mainly provided by the myoglobin meat pigments. The two major pigments are the hemoglobin that is found in the red blood cells and, therefore, is called the pigment of the blood, and the myoglobin that is a smaller molecule found in the muscle tissue. Overall, the hemoglobin molecule is basically constructed of four myoglobin subunits. The structure of the heme complex is shown in Figure 13.6. The myoglobin is a complex molecule consisting of two major parts: the protein portion called globin and the nonprotein portion called heme ring. The latter has an iron molecule in the center and is responsible for binding certain components (e.g., oxygen). The protein component consists of a globular protein attached to the iron molecule. The state of the iron molecule (i.e., reduced, oxidized) and the compounds attached to the ring affect meat color. When an oxygen molecule is attached, as is the case when the blood is carried from the lungs to the muscles, the color is bright red (Figure 13.7). This color can also be formed in chicken/turkey leg meat exposed to oxygen. The iron molecule is in its reduced ferrous (Fe^{++}) state. Consumers associate a nice red color of a fresh meat,

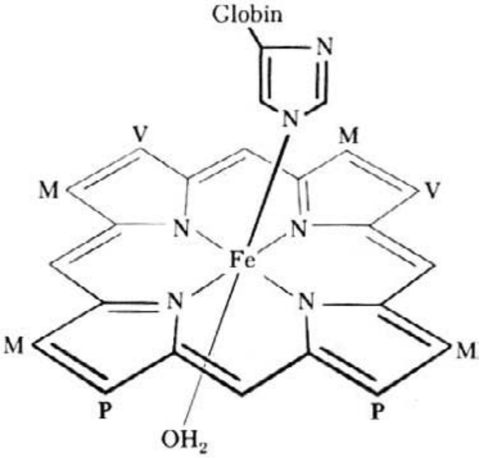

Figure 13.6. *Schematic Structure of the Heme Complex of the Myoglobin Molecule. The Globin and Water are not Part of the Planar Heme Complex. M, V and P Stand for Methyl, Vinyl and Propyl Radicals Attached to the Porphyrin Ring that Surrounds the Iron Atom. From Price and Schweigert (1987). With Permission.*

such as chicken/turkey leg meat, with high quality. In the industry, this color is referred to as "bloom" and is especially important in for marketing fresh red meats. In this state, the pigment associated with oxygen is called oxymyoglobin. The interior of the meat cut is brown, resulting from the oxidized state of the pigment (metmyoglobin in which the iron molecule is in its ferric, Fe^{+++}, form). This is due to a lack of oxygen inside the muscle, but it can be reversed when the meat is exposed to air, provided microbial counts are not too high. If a brown color appears on the surface, consumers usually associate it with old meat and will tend not to buy it. In certain markets, master packaging of fresh meat trays are flushed with CO_2 and shipped to stores to extend the shelf life of the product. In such a case, it is essential to remove the master packaging and allow some time for the "bloom" to develop (e.g., 15–30 minutes) before the meat is displayed. (Note: the packaging material of the individual trays should be oxygen permeable). As can be seen in Figure 13.7, the change between metmyoglobin and oxymyoglobin is reversible under normal conditions. However, when microbial counts are high, the return to the oxymyoglobin state is difficult to achieve because the microorganisms consume most of the oxygen and can physically degrade the pigment.

On cooking, the protein part of the meat pigment is denatured and gives the meat its typical grayish cooked color. When nitrite is added to meat, prior to cooking, as is the case in various cured meat products (e.g., turkey ham; see recipe in Chapter 9), a typical reddish color will initially develop. Later, upon heating, it will change to the stable light pink pigment called nitrosohemochrome. The difference between cured and noncured meat products can

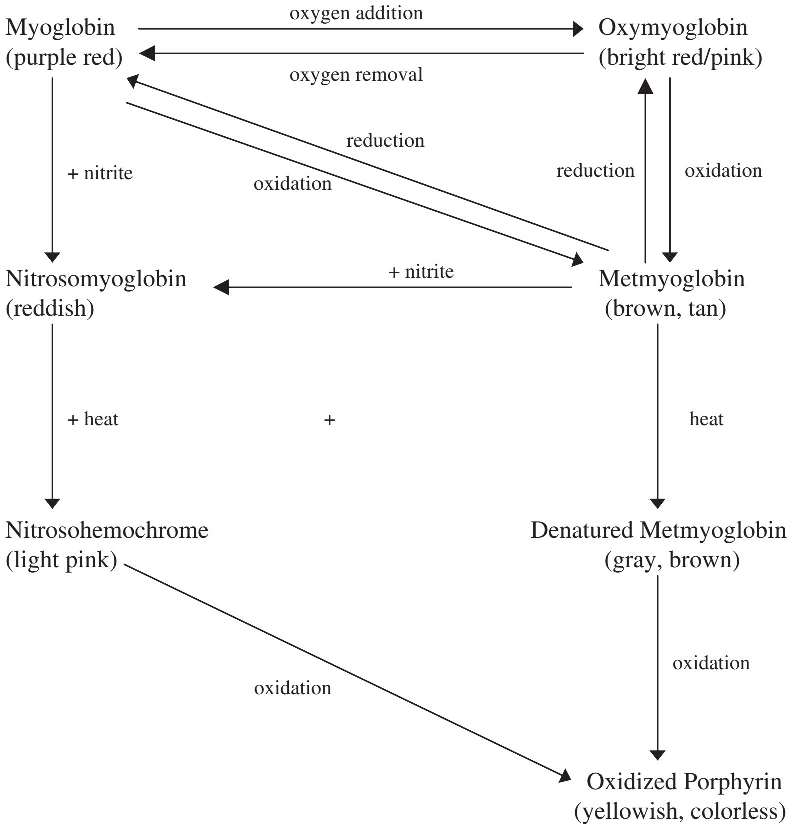

Figure 13.7. *The Different States of Myoglobin and Colors of Red Poultry Muscle (e.g., Chicken Thigh Meat). Single Arrow Represents a Nonreversible Reaction.*

be clearly illustrated when turkey leg meat is prepared at home (e.g., roasted turkey) resulting in the typical gray/brown color, or when it is cured, by nitrite (e.g., turkey ham), in a processing plant resulting in a pink cured color.

In addition, the overall color of the meat is also affected by the structure and spacing of the muscle building units—the sarcomeres. The physical structure of the sarcomeres affects the light absorbed and reflected by the muscle's surface. This has already been mentioned in Chapter 2 while discussing the differences between DFD and PSE meat, i.e., a more open structure reflects more light in PSE meat and results in a lighter appearance (Barbut, 1997; Swatland, 1989).

FACTORS AFFECTING SKIN AND MEAT COLOR

Skin pigmentation is the result of melanin deposition (i.e., pigment produced by the bird) and/or xanthophyll obtained from plant material. Numerous studies have shown that consumers commonly prefer poultry skin color that is traditionally available in their region. The skin color usually reflects local feeding practices as well as genetic stocks kept in the area (Fletcher, 1999a). In the eastern United States, deeply pigmented poultry are most desired, whereas in the northwestern United States, pale skin color is preferred. In the United Kingdom, consumers prefer a white, nonpigmented color, indicating that differences exist all over the world and are usually related to traditional market conditions.

Broilers' skin color depends on two major factors. The first is the genetic capability to produce the pigment melanin and deposit it either in the dermal or the epidermal (Figure 2.13) layer of the skin. The second factor is the genetic ability to absorb and deposit carotenoid pigments from plant material or a synthetic source. Table 13.1 shows the combinations possible to produce different skin colors. A white skin color results from no melanin or xanthophyll deposition. It should be mentioned that in most commercial strains, the ability to deposit melanin has been eliminated through genetic selection. However, on occasion, consumers return samples showing dark spots in certain regions of the skin. A quick microscopical analysis can be used to verify the presence of the typical melanin bodies in skin cells and assure the consumer that the problem is not related to microbial spoilage or any foodborne hazard. The black-skinned chicken is a strain found in China and sold in local markets. The strain has the ability to deposit melanin in the dermis and epidermis layers and, therefore, produce a very dark/black skin. Yellow skin is the result of xanthophyll present in the epidermis. Genetic strains that have the capability of absorbing and depositing carotenoids must receive pigment from the diet. Over the years, many studies have been conducted to evaluate skin pigmentation in relation to natural and synthetic sources of carotenoids and to establish dietary levels to achieve a certain coloration. In addition, it was established that the health of the flock is critical for carotenoid absorption; diseases, such as coccidiosis, can have negative effects on yellow color deposition. As shown in Table 13.1, carotenoids are deposited in the epidermis, and therefore, it is important to use a mild scalding procedure that will not damage the outer skin layer (epidermis) during scalding and feather picking (see Chapter 4). Bluish color can be seen in some strains

Table 13.1. Possible Skin Color due to Dietary Xanthophyll Being Deposited in the Epidermis or Melanin Being Produced by Malanophores. Adopted from Fletcher (1999a).

Skin Color	Epidermis	Dermis
White	None	None
Black	Melanin	Melanin
Yellow	Xanthophyll	None
Green	Xanthophyll	Melanin

and is the result of melanin deposition in the dermis (none in epidermis). A greenish color is the result of xanthophyll plus melanin (Table 13.1).

Fiber type and myoglobin content have a strong effect on meat color. The basic color differences between muscles are a result of the relative amounts of white and red muscle fibers (Table 2.2). As outlined in the table, white and red fibers have different characteristics, and the most noticeable difference to the consumer is their color. Meat color is largely dependent on the amount of meat pigment, myoglobin, present in the fiber. Chicken breast muscle is predominantly composed of white fibers, which have a low myoglobin level and, therefore, a light color. On the other hand, thigh meat is mainly composed of red fibers and shows a darker color. These differences can also be seen when measuring the actual heme content in light and dark muscles (Table 13.2). The differences in total heme, hemoglobin and myoglobin content of young broiler chickens (six weeks old) are shown in the table. The heart muscle, which appears the darkest, has the highest heme protein content followed by the *Adductor* muscle. The lightest breast muscles (*Pectoralis* and *Pectineus*) have the lowest amounts. The authors have used different methods to determine the hemoglobin and myoglobin contents (immunological, spectral photometric and size exclusion chromotography) and have also compared their results to about half a dozen other groups. The results were fairly comparable and should be of interest to researchers working on heme pigment content in poultry muscle. Different poultry species also vary in the inherited amount of pigment in their muscles (e.g., chicken vs. duck; see Table 6.6). The overall amount of myoglobin in the muscle varies depending on the species, sex, location of the muscle and the age of the bird (i.e., muscles from young animals are lighter than those from mature animals). Differences can also be related to muscle activity, where the domestic chicken breast muscle is lighter than its wild ancestor who was much more active.

Table 13.2. Total Heme, Myoglobin and Hemoglobin Content in Chicken Muscle.[1] From Kranen et al. (1999). With Permission.

Muscle	*n*	Total Heme	Hemoglogin	Myoglobin
		-------------------------------	(mg / g)	-------------------------------
Heart	9	3.75 ± 0.64[a]	2.67 ± 0.65[a]	1.08 ± 0.41[a]
Adductor	8	1.39 ± 0.31[b]	0.83 ± 0.21[b]	0.56 ± 0.17[b]
Pectineus	8	0.10 ± 0.04[e]	0.09 ± 0.04[d]	0.01 ± 0.00[c]
Sartorius	6	0.79 ± 0.12[c]	0.67 ± 0.11[b]	0.12 ± 0.02[d]
Pectoralis	10	0.24 ± 0.04[d]	0.24 ± 0.04[c]	ND

[a–e] Per parameter, means within a column with no common superscript differ significantly as analyzed by *t* test ($P < 0.05$).

[1] Values are means ± SD of the numbers (*n*) of samples indicated. ND = not detectable.

Lighting Conditions

As indicated earlier, the color that we see is the result of the light reflected from the meat's surface and, therefore, the source of light used for illumination can greatly affect the color. It should also be remembered that there are significant differences among people in their perception of colors (e.g., a person who is color blind or cannot distinguish between shades of red will have a different color perception compared to a person with perfect vision). The first time a consumer sees the color of the meat is in the store. Food store managers usually keep the meat display area well lighted to attract consumers. Different types of light sources can be used, and the three main ones include incandescent (INC), fluorescent (FL) and metal halide (MH). These sources have different spectral patterns, and the decision to install one over the other depends on factors such as energy efficiency, heat output, cost of the lightbulb and its life expectancy. For example, FL bulbs radiate about one-fifth of the heat produced by INC bulbs of the same light output and, therefore, FL bulbs can be placed inside the display cooler. A source such as MH is the most efficient to illuminate a large area, but it does not produce a full visible spectrum.

Most recent studies reporting color data of poultry meat have been based on using commercial colorimeters (Fletcher, 1999a), which employ a stable light source (e.g., xenon) to illuminate the surface after being calibrated with a white plate. This is a relatively easy method that allows absolute color values such as the CIE *L**, *a** and *b**, described before, to be collected. Such *L**, *a** and *b** color coordinates are important in studying the effects of various test parameters; however, they do not reveal the actual color the consumer will see at the store when different light sources are used. Therefore, when seeking the consumer's impression of color, it is beneficial to use scanning equipment capable of utilizing the actual light source used in the store as these light sources can significantly affect consumer preference (Table 13.3). The INC (150 W, 120 V, Extended Service, Sylvania, Danvers, MA) source was the most preferred for a whole chicken product (skin on). Employing INC was significantly preferred over using FL or MH lights. The panelists also indicated a strong preference to buy the product when presented under INC light (data not presented here), as opposed to no specific preference when presented under FL and a significant objection when presented under MH. The reason for that can be explained by examining the luminance data obtained for the INC source (Figure 13.8). The INC produces a so-called full spectrum (i.e., there is a fairly balanced distribution of the different wavelength), which imparts a full natural color to the product. The main color used by two-thirds of the panelists to describe the product under INC light was yellow. In general, the color seen is described in one to two words, indicating the main color and its shade. This is the result of summarizing all the

Table 13.3. Preference of Fresh Chicken Cuts Under Different Light Sources. All Products Presented Under 70 Foot Candle (760 Lux) (From Barbut 2001). With Permission.

Product	Incandescent	Fluorescent	Metal Halide
Whole chicken (skin on)	7.01^a	4.55^b	3.57^b
Thigh meat	6.08^b	3.65^b	4.45^b
Breast meat	5.76^{ab}	6.81^a	5.55^b

^{a,b}Means, with each row, followed by a different superscript are significantly different ($P < 0.05$) from each other. Twelve panelists evaluating the product on two successive days; 1 = dislike, 10 = like.

reflected wavelength data, in our mind, and expressing it as one color. Because we do not have the ability to "see" the individual peaks measured by the photodiode array measuring equipment (Figure 13.8), we express our overall impression.

When the whole chicken was presented under FL light (34 W, Supersaver Lite White, Sylvania, Danvers, MA), there was a reflection in the yellow zone, but two additional, strong peaks in the blue (430 nm) and green (530 nm) regions were observed (Figure 13.9); both are characteristics of this type of Lite White FL lightbulb. Reflection from a white calibration plate (data not presented here) showed the same peak pattern but with higher relative luminance intensity. The reflection curve obtained here is similar to published data for commercial FL lightbulbs (Philips, 1991) showing typical strong peaks in the

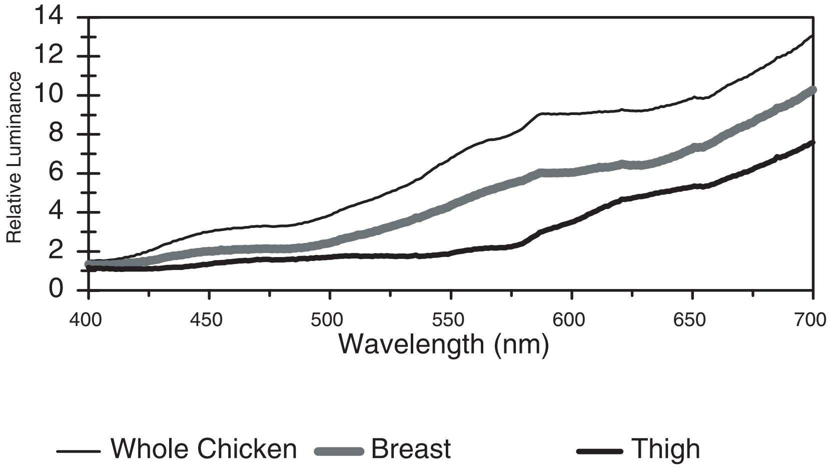

Figure 13.8. Luminance Data of Whole Chicken (Skin On), Skinless Thigh Meat and Breast Meat Presented Under Incandescent Light (760 Lux, 70 Foot Candle). From Barbut (2001). With Permission.

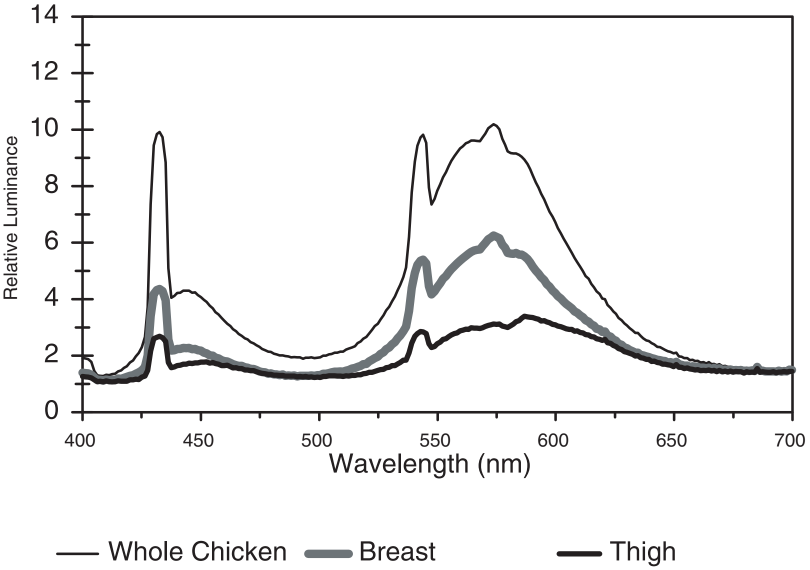

Figure 13.9. *Luminance Data of Whole Chicken (Skin On), Skinless Thigh Meat and Breast Meat Presented Under Fluorescent Light (760 Lux, 70 Foot Candle). From Barbut (2001). With Permission.*

blue (430 nm), green (535 nm) and yellow (570 nm) regions. The main color used to describe the product by three-quarters of the panelists was pale white. The reason for that was the lack of a broad enough yellow peak and the minimal red color output.

The MH luminance light source (175 W, 120 V, NL175MH-120-L, Acculite, Kitchener, Ontario, Canada) data showed a narrow peak in the yellow region (Figure 13.10), other strong peaks in the blue and green regions and a low red peak. The luminance data obtained and the position of the peaks were similar to published data of other commercial MH sources (Philips, 1991). The use of MH resulted in a low panel preference score (Table 13.3). The main color used by three-quarters of the panel to describe the product was cream white. The panelists overwhelmingly said that they would not buy the product presented under MH because of the unnatural color of the product.

Skinless chicken thigh meat with its typical dark poultry meat color was also most preferred under INC light (Table 13.3). In this case, the expression of red color could only be achieved with an adequate source of red light such as INC (Figure 13.8). The luminance curve is fairly similar to data obtained by Swatland (1989) for raw leg meat, using a fiber optic spectrophotometer. (Note: Swatland's original data was reported in absorbance units, but once converted to reflection, it is similar to the curve presented in Figure 13.8.) The presence of adequate red light output in the INC source resulted in a high buying

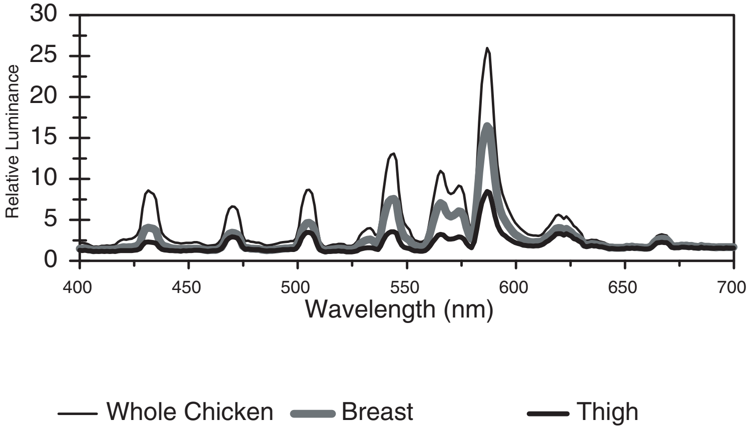

Figure 13.10. *Luminance Data of Whole Chicken (Skin On), Skinless Thigh Meat and Breast Meat Presented Under Metal Halide Light (760 Lux, 70 Foot Candle). From Barbut (2001). With Permission.*

preference as opposed to a significant lower buying preference under FL and no preference under MH. Under INC light, the leg meat was described by most panelists as pink/red. The main color used to describe the product under FL was brown, while under MH it was brown/purple. The reason for the equal buy/not buy division in the case of the MH source might be related to the presence of small red peaks (640 and 670 nm; Figure 13.10), which are not present in the FL light source (Figure 13.9).

The color of the skinless chicken breast meat was similarly liked under INC and FL light (Table 13.3). Because the color of this product is usually light beige, the red and yellow components were not as important as in the other two products. The main color used to describe the product under INC was tan/pink. Under FL, it was described as brown/beige and beige/tan under MH. Comparing the FL and MH sources showed that the product was more liked under FL light. In terms of the buying decision, there was actually a preference to buy the product under FL light ($P < 0.01$). Overall, skinless chicken breast meat has a neutral color that is not much affected by the lack of red in the FL source or the relatively strong blue and green peaks in the FL and MH sources. It should be mentioned that the luminance data obtained for the three products under the INC source are fairly similar to data obtained by a commercial colorimeter (e.g., Minolta, Hunter) capable of generating spectral data. This is because a full (or almost full) spectrum was used for illumination on both cases.

Cooking has a profound effect on meat color. As shown in Figure 13.7, the denaturation of the meat pigment during heating results in the formation of the cooked meat color, called denaturated metmyoglobin. This denaturation results in a lighter color in the case of cooked chicken thigh meat (Figure 13.11), where the entire spectral curve is elevated. This is also translated to an almost 50% increase in the *L** value (45.5 to 67.4; Table 13.4). In the case of chicken breast meat, which has a much lower myoglobin content (Table 13.2), the *L** value increased by about 60% (52.7 to 83.5; Table 13.4) due to cooking. The corresponding spectral curve (i.e., data is used to calculate the *L**, *a** and *b** values) also showed a dramatic increase (Figure 13.11). Breast meat color became yellower (6.1 to 14.5). The *a** did not change much, but the consumer will see it as a very light product. For thigh meat, the *b** increased (6.2 to 16.7) and *a** slightly decreased. The largest change was in the cooked liver *a** (13.7 to 3.3), because it has a high heme content. The denaturation caused the red to change to brown/gray.

If nitrite is added to products such as turkey ham (see recipe in Chapter 9), the typical pink cured meat color, called nitrosohemochrome, is formed. This color is very stable once the complex is formed and heated. The color values for turkey ham are provided in Table 13.4.

During slow roasting, the surface of the meat and/or skin develops a typical brown color that results from the Maillard reaction. The reaction between amino acids and reducing sugars causes this desirable browning effect. Enhancing the development of the brown color can be done by adding sugars such as honey to the basting media.

Smoking has a profound effect on obtaining a brownish golden color to the surface of the product. The four main groups of compounds found in smoke include organic acids, phenols, carbonyls and polycyclic hydrocarbons (Chapter 9). Of these compounds, carbonyls are very important in developing the brownish color, as they participate in the Maillard reaction.

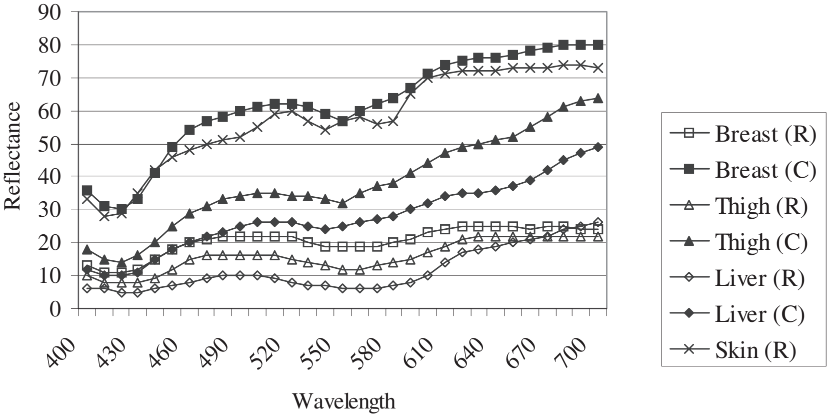

Figure 13.11. *Reflectance Spectra of Raw and Cooked Chicken Meat. R = Raw; C = Cooked. Obtained by the Use of a Minolta Colorimeter. Each Point is the Average of Two Readings at Two Locations.*

Table 13.4. Color Values (CIE *L** = Lightness, *a** = Redness, *b** = Yellowness) of Various Fresh and Processed Poultry Products. See Text for Details.

Meat	Type	Part/Area	*L**	*a**	*b**	Comments
Broiler	Raw	Thigh meat	45.58	4.40	6.26	See spectra
		Breast meat	52.75	1.36	6.12	See spectra
		Liver	35.26	13.70	4.00	See spectra
		Skin	81.66	2.88	15.08	Fairly white. See spectra
		Skin	79.28	1.24	21.47	Yellowish color
	Cooked	Thigh meat	67.41	4.87	16.77	See spectra
		Breast meat	83.57	1.93	14.50	See spectra
		Liver	59.37	3.35	16.54	See spectra
		Skin	82.72	0.00	18.16	From yellowish color skin
Turkey	Raw	Skin	80.35	0.30	9.18	
		Breast meat	50.32	2.93	5.82	
		Freezer burn	53.93	6.52	20.05	Freeze-dried area
Turkey	Franks (cooked)	Outside	52.46	27.96	31.19	
		Inside	59.51	22.24	25.16	
Chicken	Franks (cooked)	Outside	53.17	20.03	20.34	
		Inside	55.22	19.83	22.19	
		Outside + light	60.00	16.21	18.43	Exposed to light (faded)
Turkey	Ham (cooked)	Inside	64.52	11.36	7.46	
Turkey	Bacon (cooked)	Dark portion	61.86	14.02	12.46	Has dark and light meat portions
		Light portion	76.53	7.87	12.51	
Chicken	Roll (cooked)	Inside	78.45	2.26	9.45	

COLOR DEFECTS

Different color problems can be seen in fresh and cooked meat. In fresh meat, they can range from blood splashes to greening of the muscle. In addition, uneven color of breast fillets placed on the same tray can also be considered a color problem by the consumer. Several color problems can also be seen in the cooked product, ranging from nitrate burns to pinkness of the traditional white oven-roasted turkey breast products. In other cases, a problem might develop over time, such as fading or off-color formation by microorganisms producing certain pigments or oxidizing chemicals. This section will first deal with problems in fresh meat and later with cooked products. However, it should be realized that some problems in fresh meat, such as blood splashes, will be exaggerated in the cooked product.

Blood splashes and hemorrhages are related to muscle injury. When the bird is bruised or suffers bone dislocation/break, rupture of the blood vessels occurs. Using moldy feed containing mycotoxin, at a level as low as 5 ppm, has also been reported as a potential problem (Froning, 1995). During injury, cellular components are released into the muscle and cause a detrimental physiological or pathological response. The cellular components released from injured cells and blood vessels can trigger an inflammatory response and a visible blood clot. During the process, coagulation factors such as thromboplastin can cause localized or systemic vascular coagulation. In addition, the breakdown of cell membranes can result in the release of proteases and lipases enzymes and destabilize other cells (Kranen et al., 1999).

Injury can happen at different stages of the bird's life. During the growing period, birds housed in barns can injure themselves due to bumping into sharp objects, fighting or even sitting down for extended periods of time (e.g., breast blisters in heavy turkey toms). Later, during the catching and transportation operations, there is a greater risk of injury when the birds are harvested. During this process (performed manually or by a mechanical harvester; see Chapter 3), the birds are lifted and placed in crates. Injury can occur, especially if the workers do not pay attention to the prescribed procedure. Next, transportation, which can take anywhere from one to a few hours, might also result in injury, as well as can the unloading process. Gas stunning (Chapter 5) can eliminate some of the problems associated with pulling the live birds from the crates, because stunning can be done while the birds are still in the crates. Determining the time of injury is not always an easy procedure. In general, a red bruise indicates a recent injury, and a more brownish-gray discoloration on the surface can indicate an older bruise. However, in order to precisely determine the cause of the bruise, a histological examination should be used. The process involves looking at the distribution of the different red and white blood cells around the bruise (see discussion in Chapter 4). Determining the time of the bruising can help in focusing and correcting problem areas.

The hemoglobin content in muscle showing different types of hemorrhages was reported by Kranen et al. (1999). They indicated that an *Adductor* muscle showing a blood spot of several square mm (called ecchymosis) hemoglobin ranged from 6.5–9.9 mg/g of tissue. Table 13.2 shows that the average level of hemoglobin, after normal bleeding, is 0.83 mg/g. Therefore, the hemorrhage they studied showed more than a tenfold increase in the pigment present. In the *Pectineus,* myoglobin level in an area showing a blood stain (described by the authors as a small, straighted hemorrhage) was 0.12 mg/g as compared to hemorrhage-free muscle with 0.09 mg/g hemoglobin (Table 13.2). In the *Sartorius,* levels of 0.75–4.61 mg/g hemoglobin were seen in bruised muscle as compared to 0.67 mg/g in hemorrhage-free muscles.

Electrical stunning at high voltage can also increase the occurrence of hemorrhages, as was discussed in Chapter 4. This can be due to severe muscle contraction and physical damage to blood vessels that can rupture.

Pale soft exudative (PSE) is seen as lighter than normal meat and results in a poor quality in terms of water-holding capacity. This is very important to the processors because lean muscle contains about 70–75% water (Table 6.6). In the case of PSE breast muscle, the meat not only has problems holding on to injected moisture (i.e., added during further processing) but also holding its own water. This can be critical when large individual turkey breast muscles are injected, tumbled and then cooked in a bag to produce a premium oven-roasted turkey breast product. Due to the poor water holding, added moisture and some of the original water would not be held within the product. At the end of the cooking cycle, the bag will have to be opened and exudated moisture drained. This reduces profits and substantially shortens the shelf life of the product.

Apparently, there are different degrees of PSE. In an extreme case, turkey breast meat will be much lighter than the normal meat (L^* value of 55 vs. 45, respectively). When selling fresh skinless breast meat fillets, such color variations will be noticeable and potentially objectionable to the consumer, as was already mentioned in this chapter. The variation in color of turkey breast meat can be seen in Figure 13.12, where the magnitude of the PSE problem was evaluated during the year in Ontario, Canada (40 flocks; 4,000 samples). Similar results were later published by Owens et al. (2000a) for turkey breast meat sampled in Texas. Seasonal effects can be seen in Figure 13.13 for the Ontario data, indicating that the hot summer months resulted in higher incidences of PSE meat; probably due to heat stress. Statistical analysis showed that the mean L^* value of the flocks processed during the summer was significantly higher than in the spring, autumn and winter, with winter having the lowest mean L^* value (i.e., least PSE meat). As reviewed by Barbut (1998), the occurrence of PSE meat has led various researchers to suggest that the problem is associated with genetically inherited stress susceptibility shown in some birds. A comparison was made to the PSE problem in pork, where a mutation in the calcium channel regulation (called the ryanodine receptor)

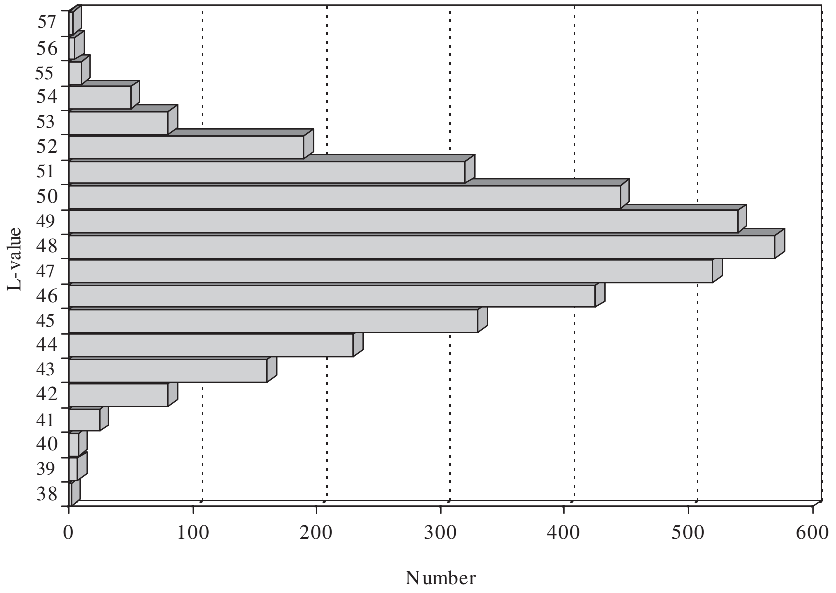

Figure 13.12. *Turkey Breast Meat Lightness (L*) Distribution; n = 4,000. From Barbut (1998). With Permission.*

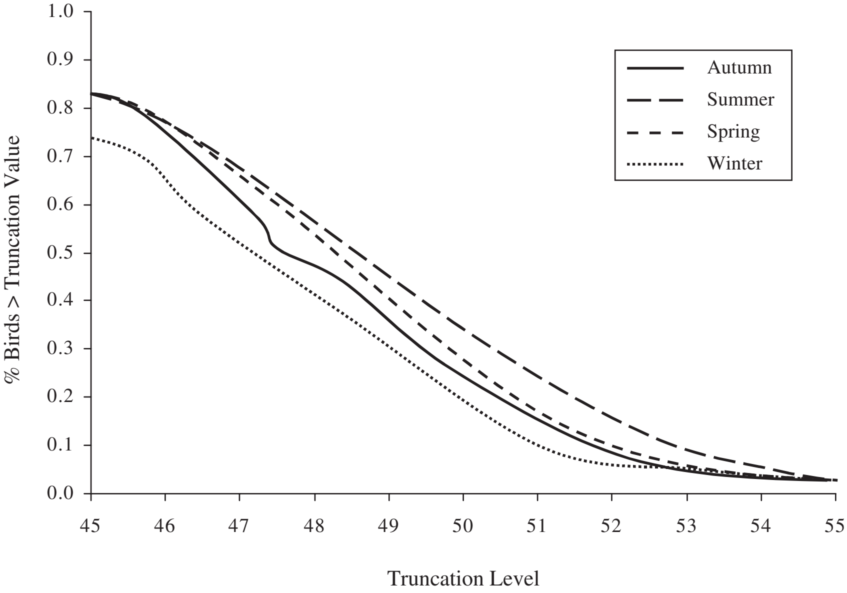

Figure 13.13. *Truncation Values of Measurements Obtained for Young Turkey Tom Breast Meat Samples Showing Seasonal Effects. From McCurdy et al. (1996). With Permission.*

was identified, a few decades ago, and used fairly successfully to remove stress-susceptible animals from the herd. However, it should be pointed out that such a gene mutation has not yet been identified in poultry. Initial work has shown some live turkeys sensitive to halothane gas (i.e., a test used to identify susceptible pigs). However, the 3.5% turkeys identified by this test (exposure to 3% of the anesthetic halothane gas for 5 minutes, at 4 weeks of age, which results in leg muscle rigidity) did not end up with a significantly higher incidence of PSE at slaughter (20 weeks), compared to a control group (Owens et al., 2000b). The authors have suggested that either the halothane response is only a limited predictor of PSE meat in turkeys exposed to stress (e.g., transportation, slaughter), or it is not an appropriate stressor to induce the PSE condition in poultry. In general, the association between halothane sensitivity and defective ryanodine receptor is well understood in pigs, but little information is available about poultry. A major difference between the two is that pigs have one isoform of the ryanodine receptor in their skeletal muscle system, whereas poultry have two isoforms. So, it may be possible that if one of the two receptors (in the turkeys tested) is normal, it can somehow compensate for the defective receptor. The pork industry is using the halothane and DNA test to identify and remove homozygous-recessive animals (both copies of the ryanodine receptor are defective). Heterozygotes with one normal receptor seem to have sufficient stress tolerance to pass the test. In poultry, with two ryanodine isoforms, the situation is probably more complex, because each copy can be independently normal or defective, and the number of potential combinations is much higher. Currently, our understanding of this problem is still insufficient to start a massive selection program. However, more research should be conducted with a long-term goal of reducing the problem in poultry flocks. It should be mentioned that the pork industry has been working on this problem for the past two to three decades and can still experience up to 20% incidences of PSE in commercial herds. Poultry processors currently starting to monitor the problem have reported incidences ranging from 5–40% PSE (Barbut, 1998; Owens et al., 2000a), depending on the season, age and cutoff point used to classify PSE meat. The latter point is very important in estimating the proportion of PSE in a flock. McCurdy et al. (1996) have suggested a cutoff value of $L^* > 50$ for young turkey breast meat (Table 13.5) based on lower water-holding capacity above this range. Owens et al. (2000a) have suggested $L^* > 53$ based on the relationships they have identified between color (L^* value), pH and expressible moisture (Figure 13.14). The problem also exists in other types of poultry, such as broilers (Figure 13.15), where different cutoff points should be used. An $L^* > 49/50$ was suggested for broiler chickens, and an $L^* > 52/53$ was suggested for mature turkey hens, which are known to have overall lighter breast meat color (Barbut, 1998).

Regardless of the reason(s) for the problem, processors dealing with PSE meat want to know how to utilize the meat with minimum interference to their

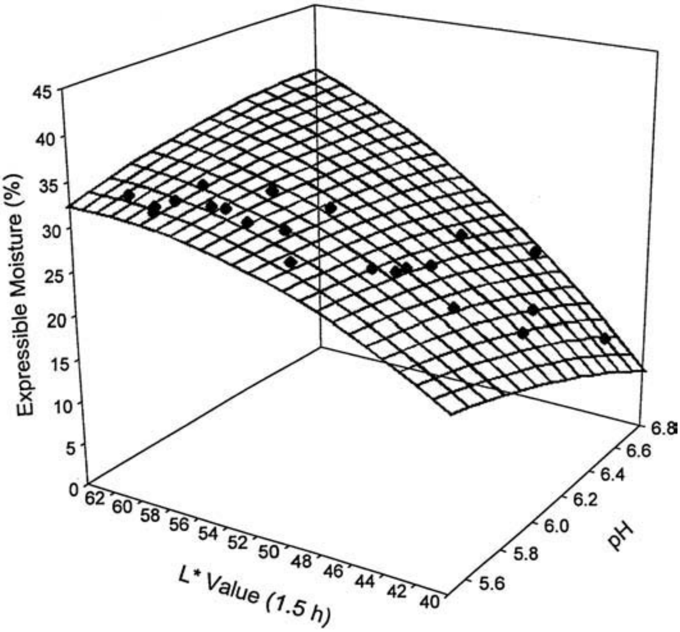

Figure 13.14. *The Relationship Between Expressible Moisture (EM), pH and L* Value (1.5 h) of Turkey Breast Fillets (EM = 14.8935 − 0.0236 * color * color − 2.5438 * pH * pH + 0.5435 * color * pH;* $R^2 = 0.3714$; $P = 0.0001$*). Each Point Represents Average pH and EM for every one increment of L* value. The surface plot represents predicted values based on raw data. From Owens et al. (2000a). With Permission.*

production. The first step is to get an idea of the magnitude of the problem and, if possible, to sort the PSE meat. Currently, most processors are using unsorted meat in large batches (called "combos") to produce a particular product. In the case of ground/chopped products, this would not be such a big problem and is actually one of the solutions (i.e., diverting the PSE meat to ground products), where the PSE meat is "diluted" with other meats. However, in a product made from large whole muscle chunks (e.g., oven-roasted turkey breast injected with 30–40% moisture; see commercial recipes in Chapter 9), the inclusion of a muscle with a severe PSE problem will result in excessive water release during cooking and, as indicated before, reduction in profit and shelf life. Overall, if processors choose to sort the meat, they should establish a cutoff point suitable for their production in terms of requirements for water holding and/or texture (see examples in Table 13.5). As discussed in Chapter 6, employing a grading system that is based on meat quality rather than the current system based on aesthetic factors (e.g., bruises, discoloration, missing parts) and confirmation can become a useful tool for processors interested in parameters such as water holding capacity.

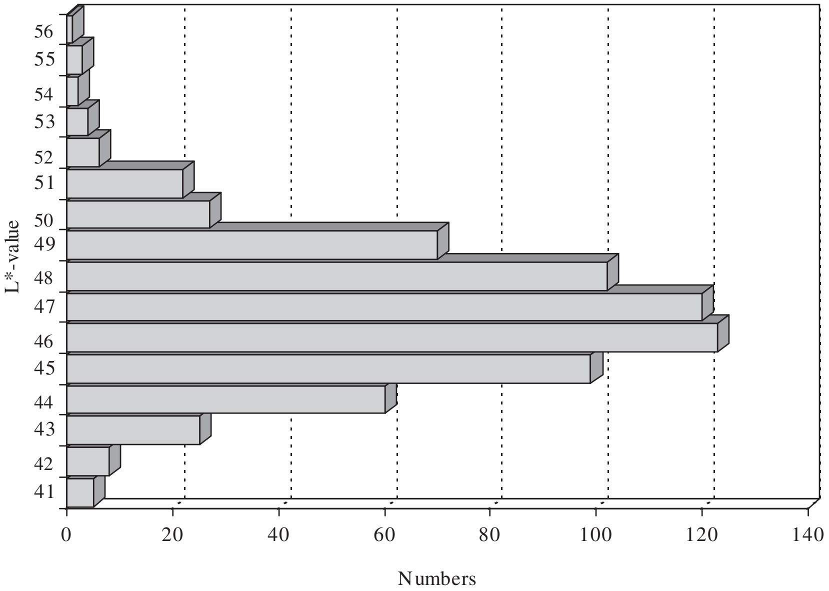

Figure 13.15. A Histogram of L Value Distributions of Breast Meat Color in 700 Chicken Broilers. From Barbut, (1998). With Permission.*

Color variation in fresh meat presentation might be perceived as a problem by consumers purchasing skin-on or skinless poultry when different color fillets are placed on the same tray. The human eye is fairly sensitive in detecting color variations in objects around us (Francis and Clydesdale, 1975), and variations in packaged poultry meat are no exception. Fletcher (1999b) reported that in a survey of 1,000 packages of skinless breast fillets (four to a package) conducted in Georgia, an average of 7% showed a noticeable color variation (i.e., presence of at least one fillet lighter or darker than the rest). Samples were evaluated at 16 different stores where packages from six brands were mar-

Table 13.5. *L** Value Cutoff Points for Water-Holding Capacity (WHC) and Compression Load (at 10 mm) Found in Young Toms' Breast Meat. From McCurdy et al. (1996). With Permission.

	WHC (%)			Compression (N)		
Season	23	20	17	26	27	28
Spring	51.3	50.9	52.0	53.3	52.1	50.6
Summer	47.1	49.8	52.9	52.9	51.8	48.8
Autumn	49.8	49.3	50.4	51.7	50.4	49.4
Winter	50.5	50.6	51.2	53.8	52.2	51.3

keted. It was interesting to note that the incidences greatly varied among brands (0.9, 3.5, 6.1, 8.4, 12.6 and 16.9% of the packages showing one or more discolored fillets). This clearly indicates that some brands are putting more effort into sorting the meat to assure color uniformity. As indicated before, the lightness of broiler breast fillets can range from $L^* = 41$ to 56 (Figure 13.15). This represents a fairly large color variation of skinless fillets that, regardless of the reason (e.g., growing, transportation stresses), can stop the consumer from buying a package showing color variation. The study by Fletcher (1999b) did not investigate the effect of color variation on consumer decision, but the fact that certain brands spend the money to assure such incidences are kept to a minimum indicates that sorting has significant economic importance.

Deep pectoral myopathy, also known as "green muscle disease," can sometimes be seen in breeder turkeys and broilers. It has been reported by some that this abnormality is an inherited defect. It is postulated that selection for increased muscle size may have altered blood flow to the deep pectoral muscle. This can eventually result in the death of muscle fibers in this area and the green appearance (Sosnicki and Wilson, 1992). On the processing line, affected birds usually show a sunken area on one side of the breast which, upon cutting, will reveal the greenish discoloration.

Freezer burn is caused by moisture loss from the surface during storage of unprotected/uncovered meat. Such dehydration causes protein denaturation and a grayish discoloration. This can result from the use of inappropriate wrapping material or holes in the packaging material. Besides discoloration, the meat in this area will be dry and tasteless and exhibit oxidative rancidity described by consumers as old/stale flavor. Table 13.4 shows color values of freezer burned turkey breast meat. The overall color became yellowish gray with a much higher b^* value compared to the raw product. The a^* value also increased by about twofold, probably as a result of concentrating the meat pigment. The area was basically freeze dried and felt rubbery after thawing.

The characteristics of the packaging material used for protecting frozen poultry are very important. It should be moisture proof and, ideally, a stretchable film that can be made to come in close contact with the meat. This is important to assure fast freezing (i.e., eliminating insulating air) and prevent water evaporation and ice accumulation inside the package. Vacuum packaging is more expensive than conventional packaging but can form into a skintight packaging and also help in minimizing oxidation during prolonged frozen storage (see Chapter 7).

Bone darkening is a phenomenon that can be induced by the freezing of young poultry. After thawing, the muscle around the bone may have a dark/bloody appearance. This is the result of bone marrow leaking from the porous bone structure of young poultry. Later, during cooking, the hemoglobin component of the marrow is heat denaturated and forms the dark discoloration. Usually, the problem is more pronounced around bone ends in the knee joint, wing joint and leg joint areas. The problem is aesthetically unpleasing but does not affect the safety and texture of the product. As indicated above, the problem is more commonly seen in young chicken fryers and seldom in mature chickens, turkeys or ducks.

Nitrite burn can be seen in cooked products that were injected in an uneven manner. This can be due to problems with the injector (e.g., blocked needles, excessive pressure) that cause an uneven distribution of the brine ingredients that is later seen as discoloration where nitrite levels were too high. This is a distinct visual defect that can be accompanied by areas that were not cured by nitrite, showing the grayish denatured myoglobin color (Figure 13.7). The appearance of such a defect usually indicates that other ingredients, such as salt and spices, have not been evenly distributed. This should be of concern to the processor, because in some areas, the anti-butolinal effect of nitrite has not been exerted.

Pinkness of cooked white meat products can sometimes be seen in further processed and thermally treated products. An unexpected pink color of a white product such as chicken/turkey breast meat will raise immediate concern in the mind of the consumer, who might think that the product has not been properly cooked. This, in turn, can result in loss of sales and consumer confidence. Maga (1994) indicated that "one of the interesting phenomenon associated with this problem is its very sporadic occurrence and even random among carcasses processed in apparently the same manner. Thus, by the time the problem is detected and various changes are made in production and/or processing, the problem has usually disappeared, and one is usually not sure as to which variable was responsible." This is often the case, but because this problem tends to come in cycles, the processor is advised to try and identify the cause.

Numerous studies have been conducted to examine different causes of the problem. Generally speaking, pink discoloration can appear throughout the product, in the seams among muscle chunks and/or around the product's perimeter. One of the most common causes is nitrite contamination. A very small nitrite concentration (i.e., 2–5 ppm) can cause a noticeable pinkness. Heaton et al. (2000) have demonstrated that the minimum nitrite level required to cause detectable pinking in turkey breast meat roll was 2 ppm, for chicken 1 ppm, for pork meat 4 ppm and for beef meat 14 ppm. The nitrate can come from the water used in the plant, from a spice mix, from gases discharged from the truck hauling the live birds and from gas-fired ovens. It has been reported that well water can have high nitrite concentrations (i.e., agricultural areas where nitrogen fertilizers are heavily used), and the problem may show after extensive snowmelt or heavy rainfall. Therefore, it is recommended that processing plants monitor the nitrite levels in their water on a routine basis. If a problem is traced to well water, special filters can be installed for water used to prepare the brine and for washing the meat.

Research has also focused on the effects of various additives. Some studies have shown that certain heme pigments are more heat stable than others. Janky and Froning (1973) studied the effect of pH and certain additives on turkey myoglobin denaturation in a model system. The type of myoglobin derivative had an effect on the amount of pigment denatured by heat in a crude myoglobin extract. Denaturation increased when pH was lowered by sodium erythorbate addition. On the other hand, sodium tripolyphosphate increased the heat stability of myoglobin by increasing the pH of the model system. Metmyoglobin was found to be more heat stable than the other myoglobin derivatives. This was postulated to be due to the increased polarity charge on the iron of the heme group. Ahn and Maurer (1990) studied the heme-complex-forming reactions of myoglobin, hemoglobin and cytochrome c (molecular weight of around 12,500 and a structure similar to myoglobin) with various ligands. They reported that naturally present ligands such as histidine, cysteine, methionine or their side chains formed solubilized protein complexes with hemoglobin, which are important factors in the pinkness of cooked meat. They also reported that a high pH (> 6.4) was favorable for the heme-complex-forming reactions of myoglobin and hemoglobin with most naturally present ligands (histidine, cysteine, methionine, nicotinamide and solubilized proteins). Heme-complex-forming reactions of cytochrome c were not affected by pH.

Ingredients such as salt and phosphate are added to processed poultry products to improve extraction of myofibrillar proteins and, hence, binding (see Chapter 9). Ahn and Maurer (1989) reported that salt (2.5%) significantly decreased the heat stability of myoglobin and hemoglobin at 68 and 74°C while it increased the heat stability of cytochrome c. Sodium tripolyphosphate (0.5%) addition, followed by heating to 68, 74, 80 and 85°C, increased the heat stability of myoglobin; however, its addition decreased the heat stability of cytochrome c due to pH increase. Dextrose, used in the same study, increased the stability of hemoglobin at 68°C and that of cytochrome c at 85°C but not myoglobin. The authors later noted that oxidation-reduction potentials decreased by adding salt and phosphate. They indicated that potential changes could have a strong effect on pinkness of cooked turkey breast, particularly if the oxidation-reduction potential of the meat is around $+90$ mV or -50 mV.

Pink color discoloration in turkey rolls was prevented by adding 3% dried milk solids (Dobson and Cornforth, 1992). The authors postulated that oxidation-reduction reactive sulfhydryls or other protein side chains of the non-fat dried milk may have raised the oxidation-reduction potential, thereby preventing complexing between denatured proteins and heme. They also indicated that casein micelles from non-fat dried milk may mask the meat pigments. In earlier work, Cornforth et al. (1986) postulated that a mixture of denatured globin nicotinamide hemochrome was responsible for pink color defects in cooked meats. They indicated that the oxidation-reduction potential was the most influential factor affecting hemochrome formation. Oxidation-reduction potential measurements on turkey meat samples indicated that hemochrome formation was promoted by reducing conditions and prevented by oxidation conditions. Slesinski et al. (2000) have also reported on the ability of various dairy proteins to reduce pink color problems.

Cooking temperature can also play a role in the pinkness problem. Time and temperature were found to be factors in determining the amount of undenatured pigment present in cooked meat (Froning, 1995). Research in red meat and poultry has indicated that the undenatured pigment in cooked meat is mainly oxymyoglobin. The USDA requires a minimum temperature of 71.2°C for all precooked poultry meat products to destroy pathogens (products are usually cooked in water, steam-cooked under pressure or heated in an oven). Cooking turkey rolls to various end-point temperatures, using a rotary oven, showed more pink color problems when end-point cooking temperatures were below 71°C. Normally, the end-point temperature should exceed 71°C, but processing temperatures could fall below this target if not closely monitored. Froning (1995) further reported a problem with regenerated pink pigment appearing 2 hours after cooling of cooked meat samples; oxymyoglobin was identified as the cause.

Color fading is caused by exposure to light that can result in oxidizing the meat pigment itself and forming oxidized porphyrin (Figure 13.7). The problem is usually more pronounced in cooked products presented in a transparent package. Fluorescent light, which has a relatively high proportion of ultraviolet light, is known to be more damaging to the color and can cause faster fading then exposure to incandescent light at the same light intensity. Numerical values presented in Table 13.4 show the extent of the fading problem in commercial turkey frankfurters exposed to UV light for one week (product kept in its original vacuum package). Overall, the product became lighter (higher L^* value) and less red due to partial oxidation of the meat pigment.

In order to minimize the problem in sensitive meat products, processors can either ask retailers to rotate the displayed packages, use a specially designed film that contains a UV light screen or use opaque packages with or without a small window. The latter might not work if the consumer is used to seeing the actual product.

Protecting the color from oxidation is desirable and can also be achieved by the use of antioxidants. Vitamin E represents the most common option, because it is a natural ingredient and can be incorporated into poultry diets without any special labeling. Vitamin E is found in different plant tissues where its function is to protect from lipid oxidation. Given in the diet, it will be distributed throughout the body and it can be stored in the tissue. Various researchers have reported the beneficial effects of vitamin E in preserving color and flavor from oxidation, as well as minimizing off-flavor formation in poultry (Sheldon et al., 1997).

Discoloration (greening, yellowing, etc.) can be caused by microorganisms present in the product. This color change is usually seen developing over time. In some severe cases, microorganisms such as *Streptococcus faecium* subspecies *casseliflavus,* can cause the development of a yellow pigment that will initially appear as tiny yellow dots but later will cover the whole surface and will appear as a layer of mustard. Such discoloration makes the product unappealing and potentially dangerous to consume. In the case of the *Streptococci,* the contamination usually takes place after cooking because the microorganism is fairly heat sensitive and is destroyed under normal cooking procedures (Whiteley and D'Sousa, 1989). Cross contamination by slicing equipment, people and contaminated air can spread the microorganism to many packages. It takes this microorganism a few weeks to develop (under refrigerated temperature), meaning that the problem will only appear later during the distribution and selling of the product.

Microorganisms such as *Pseudomonas fluorescens* can cause the development of a shiny transparent greenish exudate. Such an appearance can be mistaken to be an iridescence problem (Swatland, 1984). Microbial degradation of the heme pigment can be distinguished from the iridescence problem by rotating the product 90°. If the greenish color does not disappear, it is a pretty good indication that the problem is microbial. If the color disappears, the problem is most likely related to iridescence (see discussion below).

Green rings in a sausage-type product can indicate an improper cooking procedure. A green core indicates that the target internal cooking temperature has not been achieved, and microorganisms capable of breaking the heme-ring are still active. This kind of oxidation is irreversible and is shown in Figure 13.7. The appearance of a green ring on the peripheral part of the sausage might indicate the use of meat with a high microbial load. In such a case, the microorganisms can oxidize the heme-ring even before the cooking operation starts (i.e., before thermal destruction of the bacteria).

Iridescence, or the appearance of green-orange colors on the surface of a meat product is the result of a unique light reflection phenomenon. The exact mechanism is not fully understood, but it is known that certain muscle structures can cause optical diffraction, resulting in splitting of white light into its components. It is interesting to note that the processor can reduce or eliminate the problem by using a dull knife instead of a sharp knife for slicing. The latter is usually recommended to maintain high product quality and unnecessary breaks and tears in a sliced product. The fact that using a dull knife can "eliminate" the problem indicates that a unique smooth surface structure can induce the problem. As indicated above, distinguishing between green discoloration caused by microorganisms and a unique smooth muscle surface can be performed by rotating the product 90° and watching to see if the color disappears. If it disappears, it means that it is iridescence. A more scientific test is the evaluation of the spectral emission of the sample. In meat, the greenness due to iridescence has an almost monochromatic purity of color that is absent in even the most extreme green discoloration produced by degradation of the heme pigment (Swatland, 1984). Some people in the industry claim that the use of high phosphate levels or the use of certain phosphates can exaggerate the problem. However, not much research has been done in this area.

Battered and breaded products and potential color problems associated with them are discussed in Chapter 10.

FLAVOR OF POULTRY MEAT

Some of the most important factors in the acceptance of food are its flavor, color (previously discussed in this chapter), texture and appearance. Flavor is a combination of taste and smell that is perceived by the taste buds and the olfactory receptors in the nose (Farmer, 1999). Flavor and taste perception is a very complex system that is affected by many factors (e.g., ratio of different flavor compounds, temperature) and is still not fully understood. Taste is perceived by sensors located on the tongue capable of detecting four major tastes, namely salty, sweet, sour/acid and bitter. Other sensations such as "umami" (Japanese term meaning deliciousness), astringency, metallic and pain ("hot" and "cooling" foods) are also known. The following section will highlight some of the major findings in the area of chemicals contributing to the taste and smell of poultry meat and the effect of various production and processing practices on flavor.

Taste compounds contributing to meat flavor have been studied by various research groups. Most of the work has focused on red meat, although similar results are expected for poultry meat (Farmer, 1999). It has been suggested that proteins, peptides, amino acids and nucleotides are the most important compounds. Most are actually present at below their taste threshold concentration, suggesting that synergistic effects are important in taste perception. Fujimura et al. (1996) have analyzed the water-soluble compounds of a cooked chicken extract and later recombined some of the amino acids, metabolites of ATP and inorganic ions to try and simulate the sensory properties of the chicken extract. The process of removing individual compounds from the mixture was used to identify the contribution of each one. The major compounds were glutamic acid, inosine monophosphate and potassium ions. The glutamic acid and the inosine monophosphate conferred the "umami" and salty tastes, and the inosine also produced some sweetness. The potassium ions were responsible for salty, bitter and some sweet sensations. During cooking, a change in the concentration of reducing sugars, free amino acids and nucleotides could be seen. These changes affect the taste and aroma of poultry meat, because many of the substances are precursors for chemical reactions responsible for odor formation during cooking, roasting or frying.

Most of the odor/aroma compounds are formed during the cooking process. This is evident from the fact that cooked meat has a completely different aroma than raw meat. About 500 volatile aroma compounds have been identified in chicken meat. Many of the compounds have relatively high odor thresholds and present little contribution to the overall aroma and flavor. During the past decade, new developments in analytical equipment have allowed more precise identification of the major compounds and other low concentration compounds important in interacting with the major compounds (Shi and Ho, 1994). Table 13.6 lists the compounds that have been suggested to be the most important by various research groups employing different analytical methods. The main methods include analysis of very dilute aroma extracts by gas chromatography, together with subjective human odor assessment. Compounds detected by humans at those diluted extracts are considered to be of importance. In other studies, the thresholds of individual compounds have been established and evaluated. Different researchers have reported different compounds to be important, demonstrating the complexity of sensory perception, as well as differences in methods used for extraction, sample preparation and assessment. The compounds listed in Table 13.6 are grouped into sulfur-containing compounds, other heterocyclic compounds (containing sulfur, oxygen and nitrogen) and the group of aldehydes, ketones and lactones. Individually, such compounds can be responsible for one major aroma note such as fruity, mushroomy, meaty, sulfurous or toasted, but together they combine to provide the typical aroma of a cooked chicken (Farmer, 1999). It was indicated that the important compounds for cooked chicken aroma development are different from those important for cooked beef in that 2-methyl-3-furyl disulfide, methional and phenylacetaldehyde are less important, whereas certain lipid oxidation by-products such as trans-2, 4-decadienal and trans-undecenal are of greater importance in cooked chicken (Gasser and Grosch, 1990). Gasser and Grosch have suggested that this difference may be related to the higher concentrations of linoleic acid in chicken than in beef. Overall, it is well known to every poultry consumer that the flavor and aroma differ depending on the cooking method, indicating that certain volatiles are more important in a product prepared by roasting, frying or water boiling. However, not much information is available in the literature regarding the effect of different cooking methods (Farmer, 1999).

Among the chemical reactions important for aroma production are the Maillard reaction, degradation of the B_1 vitamin (thiamine) and lipid oxidation.

The Maillard reaction is a reaction between amino acids and reducing sugars. This reaction can result in over 100 volatile products. It represents a fairly complex sequence of chemical reactions in which one or more amino acids react with reducing sugar(s) by different pathways to yield a variety of products, some responsible for flavor and some for the browning of the surface. All of the first 19 compounds listed in Table 13.6 can be formed by the Maillard

Table 13.6. Suggested Key Compounds Contributing to Odor of Cooked Poultry Meat. Adapted from a Summary by Farmer (1999).

Compound	Odor Character	Compound	Odor Character
Sulfur-containing		3,5(2)-Diethyl-2(6)-methyl-pyrazine	Sweet, roasted
Hydrogen sulfide	Sulfurous, eggy	2-Acetyl-pyrroline	Popcorn
Dimethyltrisulfide	Gassy, metallic	**Aldehydes, ketones and lactones**	
3-Mercapto-2-pentanone	Sulfurous	1-Octen-3-one	Mushrooms
Methional	Cooked potatoes	*trans*-2-Nonenal	Tallowy, fatty
Furanthiols and disulfides		Nonanal	Tallowy, green
2-Methyl-3-furanthiol	Meaty, sweet	*trans, trans*-2,4-Nonadienal	Fatty
2,5-Dimethyl-3-furanthiol	Meaty	Decanal	Green, aldehyde
2-Furanmethanethiol	Roasty	*trans, trans*-2,4-Decadienal (and an isomer)	Fatty, tallowy
2-Methyl-3-(methylthio) furan	Meaty, sweet	2-Undecenal	Tallowy, sweet
2-Methyl-3-(ethylthio) furan	Meaty	γ-Decalactone	Peach-like
2-Methyl-3-methyldithiofuran	Meaty, sweet	γ-Dodecalactone	Tallowy, fruity
bis(2-Methyl-3-furyl) disulfide	Meaty, roasted	**Other**	
Other heterocyclic compounds		2,3-Butanedione	Caramel
2-Formyl-5-methyl thiophene	Sulfurous	β-Ionone	Violets
Trimethylthiazole	Earthy	14-Methyl-pentadecanal	Fatty, tallowy, train-oil
2-Acetyl-2-thiazoline	Roasty	14-Methyl-hexadecanal	Fatty, tallowy, orange-like
2,5(6)-Dimethyl-pyrazine	Coffee, roasted	15-Methyl-hexadecanal	Fatty, tallowy
2,3-Dimethyl-pyrazine	Meaty, roasted	4-Methylphenol	Phenolic
2-Ethyl-3,5-dimethyl-pyrazine	Roasty		

reaction. The first compound listed in the table, hydrogen sulfide, is produced by a reaction between the amino acid cysteine and dicarbonyl as part of the Strecker degradation reaction, which is part of the overall Maillard reaction. This specific reaction contributes to the overall aroma and also produces a key sulfur-containing intermediate for other reactions listed in the table.

Thiamine degradation can result in different compounds containing sulfur and nitrogen resulting from the breakdown of the vitamin bicyclic structure. Some of these compounds have a potent aroma, such as the 2-methyl-3-furanthiol compound that is responsible for a "meaty" aroma and flavor of chicken meat (Gasser and Grosch, 1990). The compound can be formed by thiamine degradation or by a reaction between cysteine and ribose. 2-Furanmethanethiol can also be formed by thiamine degradation, and it provides a roasty aroma.

Oxidation of fatty acids contributes to desirable flavors and aroma, as well as potential problems with rancidity development. Cooking results in thermal oxidation, which is responsible for generating desired flavor notes. However, oxidation occurring at ambient temperature, usually by endogenous enzymes, can result in the production of negative flavor notes, described as rancid or cardboard-like odors. Table 13.6 lists, under "Aldehydes, ketones and lactones," about 10 compounds that result from thermal oxidation (i.e., 1-Octen-3-one, trans-2-nonenal, trans-trans 2, 4-nonadienal and trans-trans 2, 4-decadienal; all are from thermal oxidation of n-6 fatty acids), all of which are believed to contribute positive flavor notes to cooked chicken. The most reactive lipids are the polyunsaturated fats, followed by unsaturated and saturated lipids. Some are also known to contribute to the unpleasant odor of reheated cooked poultry described as the warmed-over-flavor (WOF).

The overall flavor and aroma of poultry meat is influenced by the concentration of the different precursors (e.g., amino acids, sugars, lipids), temperature, pH and other chemicals present. The lack of some precursors can be a limiting factor in aroma development and may explain the bland flavor of some meats. Cooking temperature affects the extent of the Maillard reaction and oxidation of fatty acids. It has been demonstrated that the amounts of volatiles produced increases as cooking temperature is raised from 60° to 80°C (Ang and Liu, 1996). Higher temperatures can increase the rate of the chemical reactions and the release of free amino acids and other precursors. Ang and Liu (1996) showed that quantities of lipid oxidation by-products, namely, nonanal and heptanone, increased as temperature was raised from 60° to 70°C and later plateaued. On the other hand, the amounts of 2-, 3-butanedione and dimethyldisulfide increased at an almost constant rate between 60° and 80°C. Overall, the characteristic flavor of poultry is derived from the presence and concentration of various water-soluble compounds, as well as volatile aroma compounds. These compounds' concentrations and interactions can be affected by various factors including the genetic stock, sex, age and diet, as well as processing factors such as slaughter method, evisceration time, chilling rate, storage and cooking method. Some of these factors have been reviewed by Land and Hobson-Frohock (1977) and Farmer (1999). One of the most important factors, which most researchers agree upon, is the age of the bird. Other factors, such as genotype and weight, are considered by some to be extremely important. Land and Hobson-Frohock (1977) indicated that there is little evidence of statistical significance between different strains of chicken (e.g., New Hampshire crosses, Barred Plymouth Rock) when compared at a similar age. This is an important observation because comparisons made at different ages, within the same strain, have shown more significant differences. Farmer (1999) tabulated the results of some of the studies related to genotype; four studies reported that slower-growing strains provided meat with more flavor, but three other reports showed no significant difference. This illustrates the disagreement that exists among different researchers and the difficulty in fully rationalizing the impact of production factors on flavor.

As indicated before, age was shown in various studies to affect flavor, with older birds showing higher chicken flavor notes (Land and Hobson-Frohock, 1977). The effect of age can be attributed to physiological changes that occur during the growing period and, as birds reach maturity, these changes can affect the concentration of the flavor compounds/precursors. Various studies have been conducted with the Label Rouge free-range growing chickens. It was shown that flavor intensity in male chickens continually increased up to 14 weeks of age, which is the time it takes to reach sexual maturity (Touraille et al., 1981). The authors suggested that the lipid composition may be the determining factor because they did not find correlations with muscle pH, moisture content or lipid content. The sex of the bird has been reported by some to affect the flavor, with males tending to have a stronger flavor (Land and Hobson-Frohock, 1977). Others have indicated that there are usually no flavor differences among sexes until broilers reach sexual maturity at about 14 weeks of age (Touraille et al., 1981).

Diet may affect flavor, but overall large changes are required to produce a small effect on flavor (Land and Hobson-Frohock, 1977). However, some feeds, such as oxidized fats (e.g., fish oil), can induce fishy aroma in both meat and eggs when fed at a low concentration. Overall, numerous studies have been conducted to evaluate the effect of new feed ingredients on flavor, mainly to ensure no deleterious effects. In terms of enhancing the shelf life of stored poultry meat, a dietary supplement of vitamin E has been used to effectively retard lipid oxidation and off-flavor formation during prolonged storage. Sheldon et al. (1997) and other researchers have demonstrated that supplementary vitamin E can be accumulated in the muscle and later minimize off-flavor formation during fresh/frozen storage.

The effect of production procedures such as stocking density, environmental conditions and husbandry methods have been reviewed by Land and Hobson-Frohock (1977) and Farmer et al. (1997). Overall, little effect was reported once the age of the birds was adjusted. A series of studies dealing with Label Rouge broilers (i.e., slow-growing chickens, low stocking densities, high cereal diets and exposure to outside environment; see Chapter 1) showed that birds raised for a minimum of 12 weeks had a more intense odor and flavor. However, it was suggested that the older marketing age of the Label birds was responsible for this improvement in flavor (Touraille et al., 1981). A more recent study conducted in the United Kingdom with the French Label Rouge system, examining genotype, age, diet and stocking densities, showed that the most important factor was age (Farmer et al., 1997). The older Label broilers tended to have more intense flavor. Stocking density and diet showed few effects on the sensory attributes, and a significant difference due to genotype was detected (e.g., higher overall odor intensity for the Ross than the ISA 657 broiler line). Overall, the authors indicated that their study supports the idea that the improved flavor of the free-range Label chickens is mainly due to their older age.

Cooking methods can have a marked effect on the flavor and aroma of poultry meat. This is obvious to most consumers who can tell, without any difficulty, if chicken meat is roasted, deep-fat fried or cooked in water (as a soup) in their kitchen. Various researchers have reported on these differences. In one of the studies, Salama (1993) compared conventional oven cooking and microwave heating and showed conventional heating to provide preferable flavor for leg and breast meat. This may be explained by the fact that microwave heating is very fast, because it is based on friction of the fast-rotating water molecules caused by changing the polarity within the oven, and is not much affected by the thickness of the meat (see Chapter 7). This, in turn, does not allow enough time for odor and flavor development. Salama has also shown that the Maillard browning reaction is substantially reduced due to the absence of hot air circulating around the product for a sufficient amount of time. Adding sodium tripolyphosphate or sodium chloride prior to cooking also increased the flavor rating under conventional and microwave heating.

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CHAPTER 14

Measuring Sensory and Functional Properties

INTRODUCTION

ASSESSING the sensory and functional properties of food products is an important area in quality control, product development and determining consumer acceptance. The major aspects measured by researchers include flavor, texture and water- and fat-holding capacities. These aspects affect the taste, mouth feel, juiciness and overall eating characteristics of food products (appearance was discussed in the previous chapter). Poultry products showing problems with any of these areas, such as mushy texture, or water in the package, will be deemed unacceptable by the consumer. Because water usually represents the largest component in poultry and other meat products (65–80% moisture), it is essential to have a good understanding of the interactions between water, protein, fat and other additives (e.g., hydrocolloid gums).

When it comes to determining the functional properties of the product, it is sometimes difficult/confusing to choose the right method. For example, in the area of water-holding capacity, various reviews published over the last two decades have described different methods used, including modifications used by various laboratories (Hermansson, 1986; Trout, 1988; Barbut, 1996). Overall, the use of different methods represents a problem in trying to compare results from laboratories situated at different geographical locations, and sometimes even with results obtained at the same institution but produced by different groups. Attempts to develop standardized methods have emerged during the last few years. One example is a book published on methods for testing protein functionality (Hall, 1996), in which the authors suggested a standardized method for each category (e.g., solubility, viscosity, foaming and water-holding capacity).

The aim of this chapter is to review the major methods that have been used to evaluate poultry products. However, it is not intended to cover all the material published about methods to determine functional properties. A recent electronic literature search identified over a thousand articles in which key word combinations such as poultry, meat, water/fat-holding capacity and texture have been used. Therefore, only the most common methods used for poultry meat evaluation will be reviewed here. In addition, it is hoped that this chapter will contribute to better uniformity of methods used in different laboratories. This would potentially allow for more clarity and permit direct comparisons of results from different laboratories. In this chapter, some examples of using the same test with different operating parameters will be used to illustrate the difficulty in comparing results from different laboratories.

Overall, it is understood that there is no single acceptable method for all products because of their diversity. However, agreeing on one or two concepts to be used for evaluating poultry products (in each test category: texture, water and fat holding) will assist all workers in the field.

SENSORY EVALUATION

The field of sensory analysis has matured in the last half century to become a recognized discipline in food science and an important part of the food industry. Sensory professionals currently work in areas such as new product development, basic research, ingredient and process modification, cost reduction and quality control. From an industry point of view, a good sensory evaluation program can help ensure that products reach the market not only with good concepts, but also with desirable sensory attributes (Lawless and Heymann, 1998). The sensory attributes of food products encompass the senses of taste, smell, sight, touch and hearing. Taste and touch are provided by tactile senses such as mouth feel, which help us feel the food while eating. Sight relates to the overall appearance of the product, including color, which was previously discussed in the book. Hearing can also be an important stimuli that can be illustrated by the crunchiness of fried chicken and breaded products. All of these attributes influence the quality perception of the product and can be assessed by a sensory panel (Nute, 1999).

Sensory evaluation comprises a set of techniques for accurate measurement of human responses to a particular food or a consumer product (e.g., shampoo). Sensory evaluation has been defined as “a scientific method used to evoke, measure, analyze and interpret those responses to products, as perceived through the senses of taste, touch, smell, sight and hearing.”

The first term used in the definition, “to evoke,” indicates that a given set of guidelines is used for preparing and serving the samples under controlled conditions so that bias factors are minimized. For this purpose, individual test booths are used, samples are labeled with blinding codes, products must be presented in different order to each participant and food is served at a specific temperature and volume.

The second term, “to measure,” indicates that sensory evaluation is a quantitative science in which numerical data are collected to establish legitimate and specific relationships between product characteristics and human perception.

The third step is "to analyze" the results, where proper evaluation is a critical part of testing. It should be remembered that data generated from human observers are often highly variable. There can be many sources of variation that cannot be completely controlled during the test (e.g., mood, motivation, physiological sensitivity to sensory stimulation and past history and familiarity with similar products). Therefore, some screening should take place to eliminate participants with taste and color vision insensitivity.

The fourth step is "to interpret" the results. Like any other experiment, the data and statistical information are only useful when interpreted in the context of hypotheses, background information and implications for future decisions and actions to be taken. Conclusions involve consideration of the method, the limitations of the experiment and the background and context framework of the study. A sensory scientist who is preparing for a career in this area must, therefore, be trained in all four areas mentioned above. The scientist must understand the product, people, statistical analyses and interpretation of data within the context of research objectives (Lawless and Heymann, 1998).

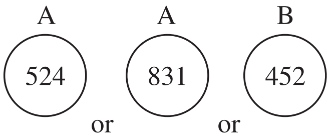
Sensory tests can be generally divided into discrimination/difference tests, ranking tests, category tests, scaling tests and profiling tests. The different tests will be described below, and, in most cases, a reference dealing with a poultry product will be provided so the reader can obtain more specific information about the test. In addition, literature describing sensory analyses and providing different designs should be consulted (Lawless and Heymann, 1998).

Discrimination/Difference Tests

These tests are relatively easy to conduct but require careful thought in their execution (e.g., as panelists may regard the idea of selecting the odd sample as a game of chance). Therefore, any differences, except the one studied, should be masked (e.g., if flavor is evaluated, appearance, color and shape must be uniform). Overall, in this type of test, the panelist is presented with the samples and is asked to identify the odd sample, match the sample to a reference or classify the samples into two groups (Nute, 1999).

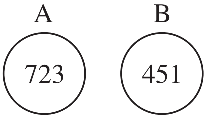
In a *triangle test,* two identical samples and one different sample are evaluated. Judges are asked to pick the odd sample from among the three samples [Figure 14.1(a)]. The test can be used to determine a difference between samples and also to select and train panelists. The three samples are presented simultaneously, where six combinations are possible in terms of presentation (AAB, ABA, ABB, BAA, BAB, BBA). It is important to randomize the sample sets so the statistical analysis will be valid. The probability of a panelist selecting the correct odd sample, by chance, is 33%. To analyze the test results, the number of correct replies is compared with those in a reference table and checked to determine if the samples are significantly different.

a) Triangle test:



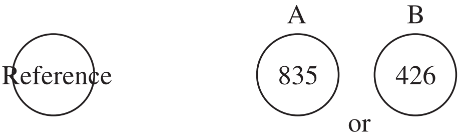
Please choose the different sample

b) Paired comparison:



Please identify the most salty/juicy/tough sample

c) Duo-trio:



Please choose the sample that matches the reference

Figure 14.1. *Common Methods Used for Sensory Difference Testing and Examples of Questions Asked. Adopted from Lawless and Heymann (1998).*

An example of evaluating poultry products was described by Dickens et al. (1994), who looked at the effect of using an acetic acid (vinegar) dip to reduce microbial counts on poultry meat. The authors used three replications of 40 carcasses each (20 control and 20 dipped in acid). The samples were cooked in water, cooked in a bag or roasted in an oven. The panelists participated in orientation sessions where they became familiar with the test objectives and the computerized system used for data entry. There were three sessions (one for each replication) held for each cooking method (i.e., six sensory sessions), with ten panelists. The results (Table 14.1) show the different samples at the panelist level, the cooking procedure (by replication) level and the cooking method (pooled replication level). For the panelist level, the duplicate sets of each panelist were pooled, so there were a total of six responses. To be significant at the 5% level, the minimum number of correct responses needed to be 5/6. Only one of the ten panelists achieved this level for each cooking method. By pooling panelists, the total number of responses by cooking

Table 14.1. Triangle Test Results of Cooked Broiler Muscles from Untreated Control Carcasses and Carcasses Treated with Food-Grade Acetic Acid (0.6%) Cooked Using Two Different Methods. From Dickens et al. (1994).

	Water-Cooked				Oven-Cooked			
	Replication				Replication			
Panelist	I	II	III	Correct/Total	I	II	III	Correct/Total
P1	—	1	—	1/6	1	—	1	2/6
P2	—	—	—	0/6	1	1	1	3/6
P3	—	—	—	0/6	—	1	1	2/6
P4	1	2	—	3/6	1	—	1	2/6
P5	1	2	1	4/6	1	—	2	3/6
P6	1	2	1	4/6	2	1	1	4/6
P7	—	1	—	1/6	—	1	1	2/6
P8	2	2	1	5/6*	1	1	1	3/6
P9	1	1	1	3/6	1	1	1	3/6
P10	1	1	1	3/6	1	2	2	5/6*
TOTAL	7	12	5	24/60	9	8	12	29/60

*Total panelist correct answers significant ($P < 0.05$).

method and replication was 20. For a significant difference ($P < 0.05$), 13 correct responses out of 20 were needed; none of the replications met this criterion. For a significant difference within each cooking method (pooled over replication), 30/60 correct responses were needed but not achieved. Therefore, the conclusion of the authors was that an acetic acid treatment did not cause any significant difference in sensory quality of the cooked meat. It should be mentioned that current guidelines call for a larger number of independent observations (i.e., >6 as used above).

Paired comparison is used to assess differences or preferences between two samples [Figure 14.1(b)]. The differences may be directional or nondirectional. Directional tests are one-sided, meaning that they are tailed tests with a question such as "which sample is more salty?, juicy? or tough?" A nondirectional test is a two-tailed test where a typical question would refer to the panelist's preference, asking which sample he/she prefers.

Van der Marel et al. (1989) used the test to look at the effect of lactic acid on decontaminating broiler meat and checking the acid effect on sensory quality. The authors used broiler leg meat from control and treated samples (submerged in 1% lactic acid for 15 seconds). The meat was grilled for 30 minutes and divided into thigh and drumstick portions, to give 48 samples per group. In their paired comparison force-choice preference test, 12 trained panelists received four pairs of coated, hot samples and were asked to indicate preference and provide the reason. Each pair consisted of one control sample and one treated sample in random order, and each panelist evaluated one pair of drumsticks and one pair of thigh meat in each of two sessions. Analyses of individual panelists for the control preference showed that one preferred the control four times, five three times, three twice, two once and one never. This distribution does not differ from that expected by chance alone. The frequencies of reasons for choosing the treated samples were stronger taste (nine times), metallic taste (twice), fatty taste (once) and fishy taste (once). For the untreated sample, it was stronger taste (11 times), fatty taste (once) and fishy taste (once). Overall, the results provided 22 choices for the treated samples and 26 for the controls, which meant no significant differences between the control and treated samples (i.e., for a significant difference at the 95% confidence level, at least 32 choices of one category should have been registered). So, the 1% lactic acid treatment reduced the bacterial contamination (see also Chapter 11), but it did not interfere with the panel's preference.

Duo-trio test is an intermediate between the triangle and paired comparison test, and it is statistically more powerful than the triangle test. According to this procedure, the panelist is presented with one reference sample and has to match it with a test sample [Figure 14.1(c)]. The probability of selecting the correct sample by chance alone is 50%, and special tables are used to determine the number of correct samples required to show a significant difference depending on the number of panelists. Janky and Salman (1986) used the test to evaluate the effect of using water vs. brine chilling. The chilled broilers were later portioned and either ice packed or chill packed (crust frozen and held at −2°C). The samples were prepared by battering, breading and deep-fat frying and allowed to cool overnight. The next day, after removing the coating material, the samples were cut into bite-size samples and assessed by 20 to 25 panelists. Training involved selection of panelists who had experience in assessing chicken meat of varying tenderness. In at least half of the taste panels, held with either light or dark meat from water-chilled carcasses, panelists were able to distinguish a significant tenderness difference between ice-packed and chill-packed products. The results paralleled those observed for instrumental tenderness (i.e., measured as shear force with a texture analyzer). The authors also noted that the panelists were able to differentiate the two packaging treatments on the basis of tenderness, even when no significant differences in shear force were noted. They suggested that this might indicate that there were other factors associated with the samples that were not measurable during the shear force analysis. A standard method for the duo-trio test was also published by the British Standards Institute (BSI, 1992) and the American Society of Testing Materials (ASTM, 1992).

In the *two out of five test,* the panelists receive five samples and are asked to sort the samples into two groups. The groups contain either three of sample A and two of sample B, or two of sample A and three of sample B, and should be served in a random fashion. Overall, there are 20 different possible combinations of the two out of five test. The test is more efficient statistically than the paired comparison test, where the chance of correctly guessing the answer is 50%, and the triangle test, where the chance is 33%. However, the disadvantage of the test is possible sensory fatigue. Overall, the panelists have to make a number of repeat evaluations that could be extremely fatiguing when they have to taste and smell the samples numerous times. This method, however, can work fairly well when samples are compared visually or by tactile methods.

The *"A" not-"A" test* is essentially a sequential-paired difference test or simple difference test. The panelist evaluates the first sample which is then removed, and then he/she receives the second sample and is asked to indicate whether the two samples are the same or different. The panelist has to remember the first sample and make the comparison without having the first sample present. The panelist does not know the number of "A" and not-"A" samples in the test. The number of correct and incorrect answers are tabulated for each sample, and the chi-squared test is used to determine if the samples are recognized as different.

Scaling Tests

These tests involve the application of numbers to quantify various sensory stimuli, such as flavor, aroma, juiciness and texture. It is through this process of numerification that sensory evaluation becomes a quantitative science subject to statistical analysis, modeling, prediction and hard theory. The numbers can be assigned by a panelist in a variety of ways: by categorization, by ranking or in ways that attempt to reflect the intensity of sensory attributes. The three most common scaling methods that have been used include the following:

- category rating, in which panelists assign numerical values to the perceived sensation based on specific and limited responses
- line scales, where the panelist makes a mark along an anchored line to indicate the strength of sensation or degree of liking
- magnitude estimation, which allows panelists to assign any number they wish to reflect the ratio between sensations

The methods differ along two important dimensions. The first is the degree of freedom provided to the panelist vs. constraint placed on the allowable responses. An open-ended scale has the advantage of allowing the panelist the freedom to choose any numerical response that seems appropriate. However, such responses are difficult to calibrate across panelists, if that is desired. Simple category ratings are usually easier to assign with fixed-intensity anchors or reference standards. Later, this facilitates calibration of panelists and data coding and analyses of the results are usually straightforward. The second dimension of difference among scaling methods is the degree of differentiation allowed to the panelists. Panelists have the freedom to use as many intermediate points along the scale as necessary, as opposed to being limited to discrete options. Usually, there appears to be a rule of diminishing returns to the number of allowable scale points. A category scale of nine or more points behaves much like the more finely graded methods of magnitude estimation and line scaling, at least when product differences are not large (Lawless and Heymann, 1998). Overall, these tests are relatively easy to use and can commonly cover a number of attributes (flavor, texture, etc.) in a single session, while many different samples can be introduced.

Category scales are one of the oldest scaling methods involving the choice of discrete response alternatives to signify increasing/decreasing sensation intensity or degree of preference. The number of alternative responses is usually between 5 to 15, depending on the application and number of graduations that the panelists can perceptually distinguish in the products. Usually, as panel training increases, perceptual discrimination of intensity improves.

An example of results obtained for emu's *M. iliotibialis cranialis* muscle are shown in Figure 14.2. For the test, meat quality traits were evaluated at different slaughter ages and different major muscles (Figure 14.2 shows only one muscle). During each session, 12 trained panelists were successively served four plates (two of the muscle reported in Figure 14.2 and two other plates with another muscle). Each plate included three meat samples arranged at random. The panelists were asked to score them for tenderness, juiciness and flavor, using a 10-point scale with zero indicating lowest intensity and 10 indicating highest intensity for each parameter. There was a significant decrease in tenderness with increasing age, while juiciness and flavor were not significantly affected by age (Figure 14.2).

Another example of this popular test is from Raj et al. (1992) who used an eight-point category scale to evaluate the effect of stunning methods on early deboned (2 hours) broilers' breast meat. A 10-member trained taste panel evaluated the cooked samples (internal 90°C) over five sessions. The arrangement of the questions is shown below:

- *Taste*—1 = dislike extremely; 2 = dislike very much; 3 = dislike moderately; 4 = dislike slightly; 5 = like slightly; 6 = like moderately; 7 = like very much; 8 = like extremely
- *Texture*—1 = extremely tough; 2 = very tough; 3 = moderately tough; 4 = slightly tough; 5 = slightly tender; 6 = moderately tender; 7 = very tender; 8 = extremely tender
- *Juiciness*—1 = extremely dry; 2 = very dry; 3 = moderately dry; 4 = slightly dry; 5 = slightly juicy; 6 = moderately juicy; 7 = very juicy; 8 = extremely juicy
- *Overall liking*—1 = dislike extremely; 2 = dislike very much; 3 = dislike moderately; 4 = dislike slightly; 5 = like slightly; 6 = like moderately; 7 = like very much; 8 = like extremely

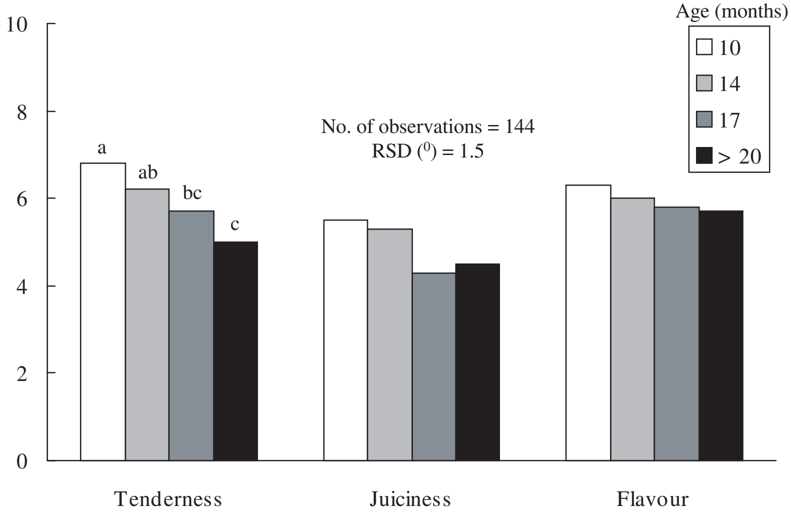


Figure 14.2. *Effect of Age on the Sensory Traits of Emu's* M. iliotibialis cranialis. *(^{0}) RSD = Residual Standard Deviation (Model Including Age, Animal and Panelist Effects). ^{a,b,c,} Means Corresponding to the Same Variate and to the Same Muscle Accompanied by Different Superscripts are Significantly Different ($P < 0.05$). Adapted from Berge et al. (1997).*

The 10-member trained panel evaluated cooked breast meat samples over five sessions. The results showed that taste and juiciness were not significantly different among the treatments, while texture and overall liking differed between argon stunning and electrically stimulated broilers. The mean ranks for texture were the highest for control, intermediate for argon stunning and lowest for electrical stimulation. The mean ranks for overall liking were similar for the control and argon stunning groups, and both ranked higher than the electrical stimulation treatment. Overall, it was concluded that stunning broilers with argon induced anoxia and produced tender breast meat when filleted at 2 hours postmortem. It should be noted that revised guidelines suggest not using a trained panel for "liking" evaluation.

Line scales are also called graphic rating scales and visual analog scales. They have become fairly popular since the advent of digitizing equipment and the widespread application of on-line computerized data entry programs. During the test, the panelist makes a mark on a line to indicate the intensity or amount of some sensory characteristics. In most cases, only the end points are marked. The anchors may be intended to help avoid end effects associated with the reluctance of panelists to use the ends of the scale. Other intermediate points may also be labeled. In some cases, a central reference point representing the value of a standard or baseline product is marked on the scale, and test products are scaled relative to the reference. Line scale techniques are very popular in descriptive analysis of multiple attributes by trained panels but have seen less applications in consumer research (Lawless and Heymann, 1998).

A study by Oltrogge and Prusa (1987) examined the effect of variable power settings used in microwave cooking on the eating quality of chicken meat. An example of the line scale is provided in Figure 14.3 where a 15 cm unstructured line scale, labeled at each end, was used. Samples of chicken breast were cooked to an internal temperature of 82°C at either 40, 60, 80 or 100% power in a 600 W microwave oven. The authors reported that cooking at 60% power resulted in the most tender samples, and this was correlated with instrumental texture evaluation by a texture analyzer. There were no significant differences in the other attributes investigated.

In another example, Caron et al. (1990) used a 15 cm line scale with anchor points at 1.5 cm from each end of the line. They used mass selection (17 or 20 generations) in three lines of Japanese quails and looked for selection response in terms of body weight, carcass composition, cooking properties and sensory characteristics. Table 14.2 shows their results, which indicated that there was a significant line effect on tenderness and juiciness. Sex (male vs. female) was not found to be a significant factor after 45 days. Flavor was also not shown to be affected by line. These two observations support the previous discussion, mentioned earlier in the book, about the effect of sex and

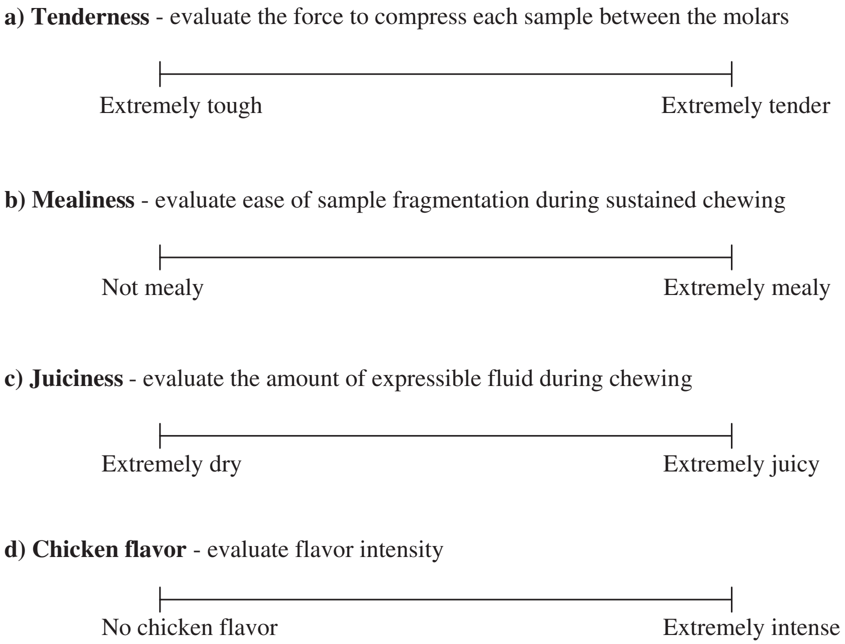

a) Tenderness - evaluate the force to compress each sample between the molars
Extremely tough
Extremely tender
b) Mealiness - evaluate ease of sample fragmentation during sustained chewing
Not mealy
Extremely mealy
c) Juiciness - evaluate the amount of expressible fluid during chewing
Extremely dry
Extremely juicy
d) Chicken flavor - evaluate flavor intensity
No chicken flavor
Extremely intense

Figure 14.3. *Example of Unstructured Line Scales Used to Evaluate the Effect of Variable Microwave Power Setting on Heating of Chicken Breast Meat. Redrawn from Oltrogge and Pursa (1987).*

Table 14.2. Effects of Japanese Quail Line on the Cooking Properties of Carcasses and on the Sensory Characteristics of Meat from the *Pectoralis major* Muscles in Lines Selected for High Body Weight at 45 Days of Age—Lines 1, 2 and 3 or Line C (the Unselected One). Adopted from Caron et al. (1990).

Variable	Line 1	Line 2	Line 3	Line C	SEM
Tenderness[1]	8.5^{a}	7.9^{a}	6.7^{b}	7.9^{a}	.26
Juiciness[2]	6.7^{ab}	6.5^{ab}	6.1^{b}	7.1^{a}	.22
Flavor[3]	7.9	8.2	7.7	8.0	.18
Oven-ready weight, g	189.7^{a}	197.0^{a}	147.8^{b}	109.3^{c}	3.19
Weight loss, %	16.3	18.2	16.3	16.6	.74

[a–c] Means within a row with no common superscript are significantly different ($P \leq 0.05$).

[1] Tenderness values on a 15-point scale; 1 = slightly tender, 15 = very tender.

[2] Juiciness values on a 15-point scale; 1 = very dry, 15 = very juicy.

[3] Flavor values on a 15-point scale; 1 = slight, 15 = intense.

genetic line on poultry meat flavor (see Chapter 13). The oven-ready weight was highest for lines 1 and 2, intermediate for line 3 and lowest for line C (unselected control). The meat from line 3 was not as juicy and not as tender as that from line C. For lines 1 and 2, the meat had intermediate juiciness and was as juicy as the meat from line C. Overall, juiciness and tenderness were associated with the relative proportion of fat and protein in the carcass (results not presented here). Line 3 had the leanest birds and, overall, produced acceptable meat, but it was slightly drier and significantly tougher than that for the other lines selected for high body weight.

Magnitude estimation is another technique for scaling that involves unrestricted application of numbers to represent sensation ratios. In this procedure, the panelist is allowed to use any positive numbers and is instructed to assign them so that the ratios between the numbers reflect the ratios of sensation magnitudes experienced. For example, if a chicken frankfurter is given a value of 10 for saltiness intensity, and product B seems twice as salty, product B is given a magnitude estimate of 20. The test does not depend on visual appearance of the ballot in any way, as do the category scales and line marking techniques. Rather, the critical points in applying the method are the instructions given to the panelist and the data analyses techniques. There are basically two variations of the test, with the first employing a standard stimulus given to the panelist as a kind of reference or an anchor (the standard is generally assigned a fixed value for the numerical response). In the second variation, no standard stimulus is given, and the panelist is free to choose any number he/she wishes; all samples are then rated relative to this first intensity.

An example of the instructions given for such a test is found below:

> Please taste the first sample and note its saltiness. This is a reference sample that is assigned the value of -10- for its saltiness intensity.
>
> Please rate all other samples relative to this reference, applying numbers to the samples to represent the ratio of saltiness intensity among samples. For example, if the next sample were twice as salty, you would assign it a value of -20-, if half as salty, assign it a value of -5-. You may use any positive number including fractions and decimals.

Values of zero are sometimes allowed in this method, as some of the products may in fact have no saltiness, or no other sensation that is being rated on a given attribute (Lawless and Heymann, 1998).

Profiling/Descriptive Analysis

This group of methods provides one of most sophisticated tools in the arsenal of the sensory scientist. The methods assist in obtaining complete sensory descriptions of a product, they help in underlining ingredient and process variables and they determine which sensory attributes are important for acceptance. Overall, there are several different descriptive analysis methods, which in general, reflect different sensory philosophies and approaches. Depending on the specific technique used, the description can be more or less objective, as well as quantitative or qualitative. This set of methods is useful in situations where a detailed specification of the sensory attributes of a product, or a comparison among several products, is important. Descriptive analysis can indicate exactly how, in the sensory dimension, one product is different from the other (e.g., yours vs. a competitor's product). These methods are commonly used in the product development stage to measure how close a new entry is to the target or to assess suitability of a prototype product. One of the most important things is the language used. Therefore, during the training phase, there is an effort to teach the panelists or have the panelists create their own scientific language for the product category of interest (Lawless and Heymann, 1998).

Terms to profile the flavor and aroma of fresh and reheated chicken meat were developed by Lyon (1987). Initially, a free word association list was developed by the panelists and resulted in 45 descriptive terms that included words such as chickeny, meaty, gamey, roasted, boiled, toasted, brothy, bouillon-like, liver-organy, earthy, greasy, cooked vegetable, moldy, nutty, cardboardy, stale, reheated, fatty, oxidized, fishy, metallic, chemical and astringent. The panelists then evaluated freshly cooked chicken patties (50% light meat and 50% dark meat) and reheated patties after 1, 3 and 5 days of storage. The terms were used to obtain intensity data and frequency of use for statistical analyses and later to determine appropriateness of the terms for profiling and discriminating among fresh and reheated samples. The initial list was reduced to 31 terms. Factor analysis was then employed as a means of grouping terms together according to the newly created factors. Eight factors were extracted that could explain 77% of the variation in the data. These were further reduced after discussion with the panelists and applying further factor analyses. In addition, the redundant terms were eliminated by variable cluster analysis and stepwise discriminate analysis to 12 terms listed in Table 14.3. This process illustrates the challenges in developing an appropriate sensory questionnaire concerning flavor, which is one of the most complicated areas because so many chemical compounds are involved (see Table 13.6).

Another example is the development of the cobweb or spider plot of the *Quantitative Descriptive Analysis (QDA),* which was developed in the early 1970s. In contrast to the flavor profile analysis, the data are not generated through consensus discussions, and panel leaders are not active participants. In this case, unstructured line scales are used to describe the intensity of rated attributes. Lyon and Lyon (1993) developed an attribute profile to study the effect of deboning time (2 and 24 hours postmortem) of samples cooked in water or on a belt-grill oven. The list of attributes developed is shown in Table 14.4. Their factor analysis showed that two primary categories of sensory attributes explain about 84% of the variation. Factor 1, which included the

Table 14.3. Twelve Sensory Descriptive Terms with Definitions Developed for Evaluation of Chicken Flavor. From Lyon (1987). With Permission.

Term	Definition
	Aromatic/taste sensation associated with:
Chickeny	• cooked white chicken muscle
Meaty	• cooked dark chicken muscle
Brothy	• chicken stock
Liver/organy	• liver, serum or blood vessels
Browned	• roasted, grilled or broiled chicken patties (not seared, blackened or burned)
Burned	• excessive heating or browning (scorched, seared, charred)
Cardboardy/musty	• cardboard, paper, mold or mildew; described as nutty, stale
Warmed-over	• reheated meat; not newly cooked or rancid/painty
Rancid-painty	• oxidized fat and linseed oil
	Primary taste associated with:
Sweet	• sucrose, sugar
Bitter	• quinine or caffeine
	Feeling factor on tongue associated with:
Metallic	• iron/copper ions

mechanical geometrical characteristics (i.e., hardness, chewiness, fibrousness and particle size and shape), explained 64% of the variation and separated the treatments based on deboning time. Factor 2 explained 20% of the variation, which was related to moisture characteristics, and discriminated the samples based on cooking method.

Lyon and Lyon (1997) later used the same profile to investigate the relationship between sensory descriptive profile and shear values of chicken breast meat deboned 2, 6 and 24 hours postmortem. Their results presented as a cobweb presentation are shown in Figure 14.4 with the different deboning times. Sensory descriptive texture attributes were separated by variable cluster analyses into five groups representing mechanical, moisture, chewdown, saliva and residual characteristics. They found differences in texture between the different deboning times of the fillets. The mechanical characteristics, excluding breakdown, in cluster I were highly related to shear force values measured by two instruments (Warner-Bratzler and Allo-Kramer). The authors' overall conclusion was that meat texture is highly complex, and instrumental methods can only provide one dimension of texture (i.e., the one involved in mechanical breakdown in this case). Whereas, sensory perception of texture also involves aspects that as of yet cannot be directly related to instrumental methods.

Table 14.4. Attributes, Definitions and Terms Used to Anchor Scales Developed for the Texture Profile of Breast Pieces Deboned at 2 or 24 Hours and Cooked Either in Water or on a Belt-Grill Oven. From Lyon and Lyon (1993). With Permission.

Attribute	Definition	Anchor Terms
Wetness	Degree of moisture on surface	Dry to wet
Springiness	Degree that sample returns to original shape after partial compression	Low to high
Initial cohesiveness	Deformation before rupture	Low to high
Hardness (1)	Force required to bite through to rupture the sample	Low to high
Initial juiciness	Amount of moisture in the meat	Low, dry to high, wet
Rate of breakdown	Rate that sample mass breaks down into individual components	Slow to fast
Hardness (2)	Force necessary to continue biting through sample	Low to high
Chewiness	Amount of work to chew sample (hardness × cohesiveness × chewiness)	Low to high
Persistence of moisture release	Degree that moisture release persists or continues during chewing	Low to high
Cohesiveness of mass	How sample holds together during chewing (low = fibers break easily, wad dissipates to high = wad grows in size, resists breakdown)	Low to high
Saliva produced	Amount of saliva produced in the mouth during sample manipulation to mix with sample to ready it for swallowing	None to much
Particle size and shape	Description of size-shape of particles as sample breakdown continues on chewing	Fine, small to coarse, large
Fibrousness	Degree of fibrousness or stringiness	None to very much
Chew count	Number of chews to get sample ready to swallow	
Bolus size	Size of wad at point of swallowing	Small to large
Bolus wetness	Amount of or feel of moisture in wad at the point ready for swallowing	Dry to wet
Ease of swallow	Easy to hard	Easy to hard
Residual loose particles	Amount of loose particles left in mouth after swallowing	None to many
Toothpack	Amount of sample packed in or around teeth	None to much
Mouthcoating	Amount of moisture-fat coating the oral cavity after swallowing	Low to high

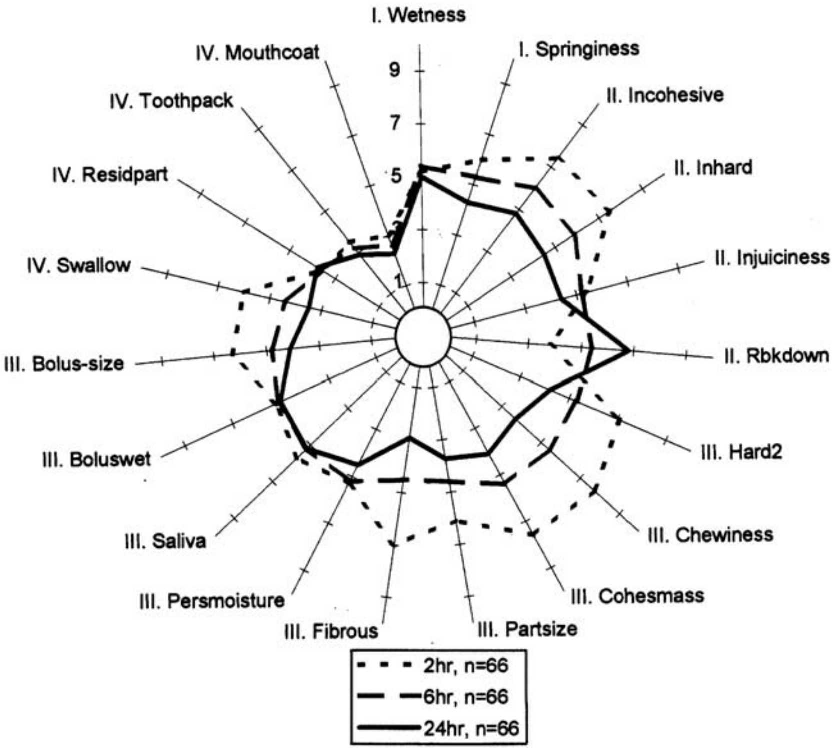


Figure 14.4. *Sensory Descriptive Profile of Texture Attributes of Broiler Breast Samples Deboned at Postmortem Times of 2, 6 and 24 Hours. Each Ray, Originating at the Center Polygon (0 Point) and Extending to the Attribute Label, Represents the 0 to 15 Linear Response Scale, Truncated to 10 Points. Each Ray is Labeled with the Attribute Abbreviation and Phase of Evaluation. Mean Values (n = 66) for Each Attribute for a Postmortem Treatment are Connected to Depict the Sensory Texture Profile. Ray Labels:* Phase I—*Wetness and Springiness Were Evaluated during the Initial Compression with Molars;* Phase II—*Incohesive (Initial Cohesiveness), Inhard (Initial Hardness), Injuiciness (Initial Juiciness), and Rbkdown (Rate of Breakdown) Were Evaluated during the Initial Compression with Molar Teeth;* Phase III—*Hard 2 (Hardness After 15 Chews), Chewiness, Cohesmass (Cohesiveness of Mass), Partsize (Particle Size/Shape), Fibrous, Persmoisture (Persistence of Moisture Release), Saliva, Boluswet (Bolus Wetness) and Bolus-Size Were Evaluated After 15–25 Chews; and* Phase IV—*Swallow, Residpart (Residual Particles), Toothpack and Mouthcoat Were Evaluated at the Point of Swallowing. From Lyon and Lyon (1997). With Permission.*

Overall, the descriptive methods are very useful in examining individual components contributing to flavor, texture, etc. However, it is extremely important to include a precise description of the terms used for evaluation as well as other parameters used for the experiment (e.g., deboning time, freezing, thawing, cooking time and procedure) to enable other researchers to compare results. Developing profiles and training are time consuming and fairly expensive; therefore, attention to detail, well-designed experiments and proper selection of terms can increase the benefits from the experiment.

TEXTURE

Determining the textural parameters of a poultry product is important in optimizing growing and processing conditions so an acceptable product can be offered to the consumer. In the area of fresh products (e.g., chicken breast, turkey thigh meat), a product that is too tough to chew is unacceptable to the consumer as is a product that is too mushy and falling apart. The textural parameters can be measured by different tests that basically include shear, penetration, compression, tension and torsion (Figure 14.5). Another test that is used more for research purposes is dynamic scanning rigidity monitoring, which employs low strain (i.e., nondestructive testing). The test is mostly used for monitoring the gelation process (i.e., during heating) and interactions

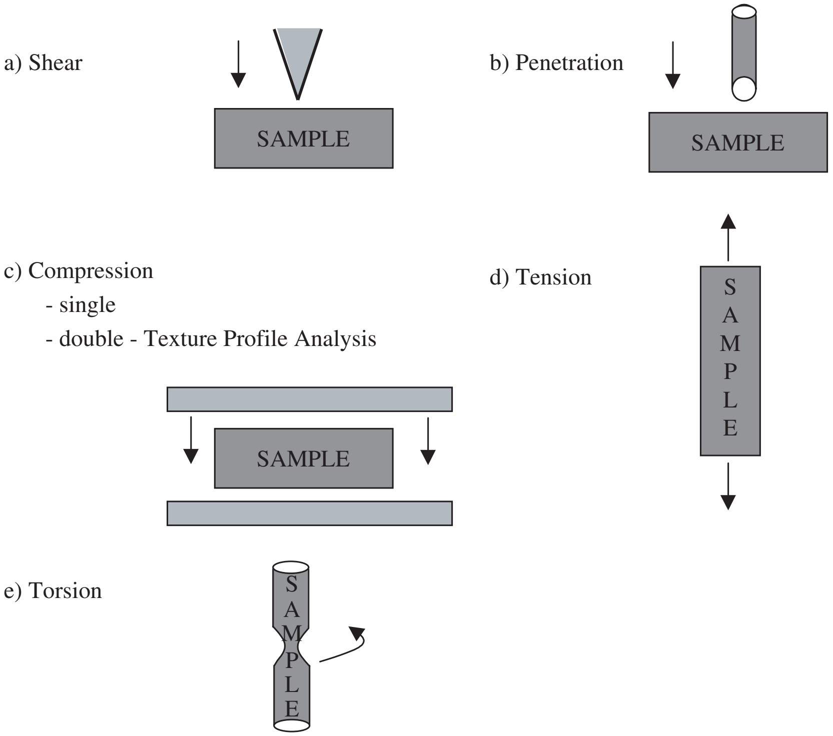


Figure 14.5. *Different Modes of Texture Analysis.*

between different meat and non-meat gelling components, as will be described below.

Shear Test

Shear test is one of the first tests developed to determine the toughness of meat. One of the most known tests is the Warner Bratzler, named after the person who developed it in 1949, which employs a single blade used to cut a core meat sample and provides the peak force required to shear the sample [Figure 14.5(a)]. Instrumental determination of texture, or tenderness, is usually evaluated on intact pieces or cores large enough to ensure representative sampling of the muscle so that treatment effects can be accurately measured. Bratzler (1949) noted that sample size, location within the muscle, orientation of the fiber to the shearing blade and presence or absence of connective tissue were critical to ensure reliable results with the Warner-Bratzler shear device (WB). A second device used to evaluate food texture is the Allo-Kramer shear device (AK) introduced in the 1950s. It has been adapted to meat texture and is routinely used by researchers and quality control personnel. The same considerations of size, location and fiber orientation have been noted for the AK as with the WB. The AK employs a cell consisting of 10 to 13 blades guided into a square box to shear the sample. Lyon and Lyon (1996) compared the effect of broiler breast meat deboning time by using both the WB and AK shear methods and correlated the results with a sensory panel (Table 14.5). For the WB, intact 1.9 cm wide strips of cooked meat were evaluated. For the AK, 20 g strip portions of 1 cm^2 (top size) were evaluated. Sensory characteristics were evaluated by category scales-untrained panel (results reported in Table 14.5) and descriptive analysis-trained panel (results not presented here).

The shear values of both the intact (WB) and diced (AK) samples indicated significant differences due to deboning times (Table 14.5). Both shearing procedures were sensitive enough to discriminate differences between each of the three deboning times. As indicated by the authors, reduction in shear values as postmortem deboning time increases is well documented in the literature. The sensory panel also reported the same trend, and the results for tenderness were highly correlated with both instrumental methods (Table 14.5). Juiciness was not found to be affected by deboning time. The overall texture acceptability was significantly affected by deboning time and also showed high correlation with both instrumental methods.

Penetration

In this test, a small-diameter probe is descended into the product at a constant rate [Figure 14.5(b)] with the force required to rupture the sample being recorded. A variety of different probes have been used, including flat and

Table 14.5. Warner-Bartzler and Allo-Kramer Shear Values for Intact and Diced Cooked (80°C) Samples of Broiler Breasts Deboned at Three Postmortem (PM) Times and Sensory Values (Category Scale-Untrained Panel) of Cooked Diced Chicken. Adapted from Lyon and Lyon (1996).

	Texture		Sensory		
Deboning Time	Warner-Bratzler[1] (intact)	Allo-Kramer[2] (20-g dice)	Juiciness[3]	Tenderness[3]	Acceptability[4]
(h PM)	(kg)	(kg/g)			
2	9.5 ± 3.9^{a}	5.2 ± 1.0^{a}	3.5 ± 1.3	2.5 ± 1.3^{c}	2.0 ± 0.9^{c}
6	4.7 ± 1.6^{b}	3.4 ± 0.8^{b}	3.4 ± 1.2	3.8 ± 1.2^{b}	2.6 ± 0.9^{b}
24	3.2 ± 0.9^{c}	2.2 ± 0.2^{c}	3.5 ± 1.3	5.1 ± 0.8^{a}	3.0 ± 0.9^{a}
Correlations (*r* values)					
With Warner-Bratzler			0.06	−0.90	−0.92
With Allo-Kramer			0.00	−0.99	−0.93

[a–c] Values (X ± SE) within a column with no common superscript differ significantly ($P \leq 0.05$). For texture, mean values are averages of 66 observations (22 birds × 3 replications) for each deboning time; for sensory, 22 panelists × 3 replications

[1] Benchtop Warner-Bratzler device was used to shear a 1.9 cm-wide intact strip

[2] Multiple-bladed Allo-Kramer attached to an Instron was used to shear 20 g of diced sample

[3] Category scales: 1 = very dry, tough to 6 = very juicy, tender

[4] Category scales: 1 = poor to 5 = excellent

rounded tip at different diameters. The test can be used to determine the resistance to puncture a cooked whole muscle or comminuted products. The results are usually used to compare relative toughness. This is an easy test to employ, and some companies use it on a routine basis as a rapid quality control test. The gelatin industry, for example, uses the test to standardize gelatin strength, also known as "bloom." Another area where this test can be very useful is in the monitoring of changes in a raw meat batter during cooking. The test is attractive for this purpose because the researcher starts with a paste-like, raw meat batter that stiffens during the cooking operation. An example of results obtained for a poultry meat batter prepared with either salt (2.5%) or low salt (1.5%) plus phosphate (0.42%) are provided in Table 14.6. The raw meat batter showed low penetration values (using a 9 mm diameter flat tip probe attached to a texture analyzer) that could not be determined by a shear test because of the flow characteristics of the sample. The transition from a viscous to an elastic sample was clearly seen at the point where myofibrillar protein starts to gel at about 50 to 55°C. The effect of lowering the NaCl level and using tripolyphosphate (TPP) can also be seen, where textural changes were similar up to 55°C but later increased at a slower rate for the phosphate treatment. The amount of extractable proteins was used to evaluate the quantity of proteins going into structure building (i.e., gelling). As temperature was raised, the amount decreased at about the same rate in both the high- and low-salt treatments. However, the differences observed in penetration force suggest that the extent of protein binding differed among the two systems.

The changes can also be followed by microstructure evaluation. Figure 14.6 illustrates the changes in the 2.5% NaCl gel during cooking from 20–70°C, employing the same temperature intervals shown in Table 14.6. The micrographs taken during the different stages of cooking show a progressive change in the batter's microstructure. The batter showed an organized gel structure at room temperature. This kind of structure has been previously reported in meat batters and indicates that a matrix arrangement exists prior to cooking. On heating to 40°C, the protein strands became thicker while pore size stayed the same [Figure 14.6(c)]. A further increase to 55°C resulted in an increase in the number of connections among protein strands. The junction zones between strands also became thicker. In addition, thin protein strands were visible among the thick strands, which increased the density of the protein matrix. These changes corresponded to the large increase in gel strength observed at this temperature (Table 14.6). Further heating to 70°C results in a denser protein matrix, which was a result of the formation of additional protein strands concurrent with a reduction in pore size. Wang and Smith (1992) have also reported that in a salt-soluble protein solution (30 mg/ml, at pH 6.5) heated to 55°C, aggregates composed of globular structures connected by strands were observed in scanning electron microgrpahs. When temperature

Table 14.6. Effect of Salts and Heating Temperature on Gel Strength, Measured by a Penetration Probe, and Amount of Extractable Protein. From Barbut et al. (1996). With Permission.

Treatment Temperature (˚C)	Penetration (N)		Extractable Proteins (mg/ml)	
	2.5% NaCl	1.5% NaCl* + 0.42% TPP	2.5% NaCl	1.5% NaCl[a] + 0.42% TPP
20	30.8[f]	25.3[f]	1.62[ab]	1.72[a]
40	43.3[ef]	40.1[ef]	1.58[b]	1.60[b]
50	60.0[e]	60.5[e]	1.38[c]	1.50[b]
55	189.0[d]	194.1[d]	1.18[de]	1.21[d]
60	356.6[b]	287.5[c]	1.07[e]	1.08[e]
70	475.8[a]	373.3[b]	0.37[f]	0.40[f]

[*] Both the 2.5% NaCl and 1.5% NaCl + 0.42% phosphate treatments were formulated with the same ionic strength (*M* = 0.42).

[a–f] Means followed by the same superscript letter, within each test category, are not significantly different at 95% level.

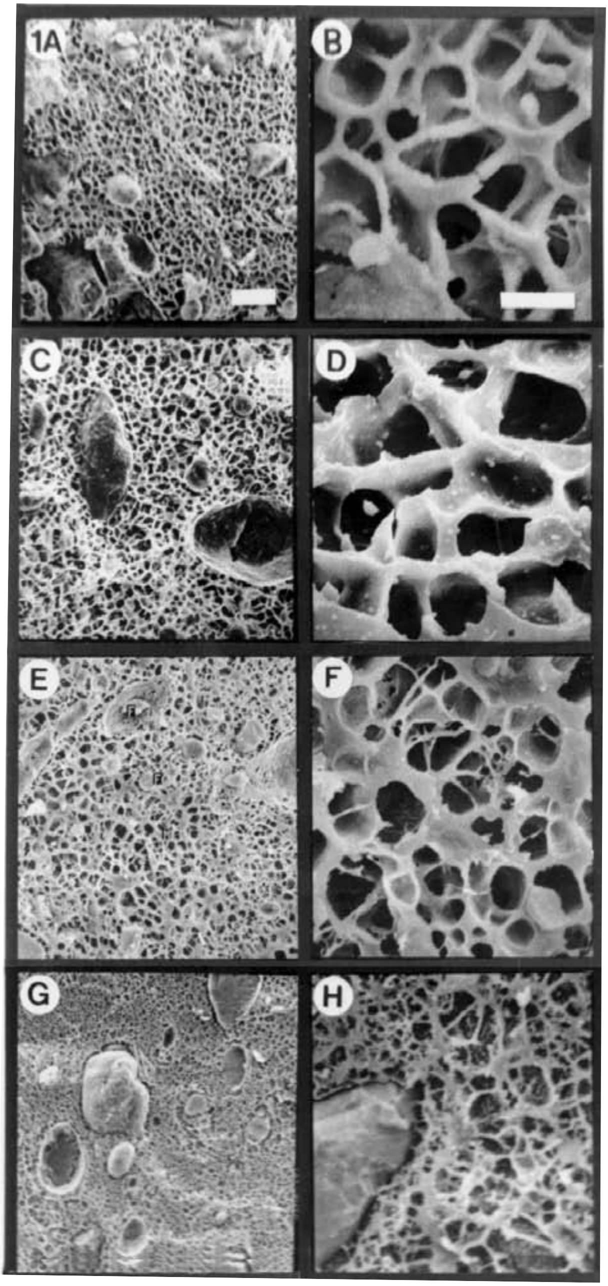


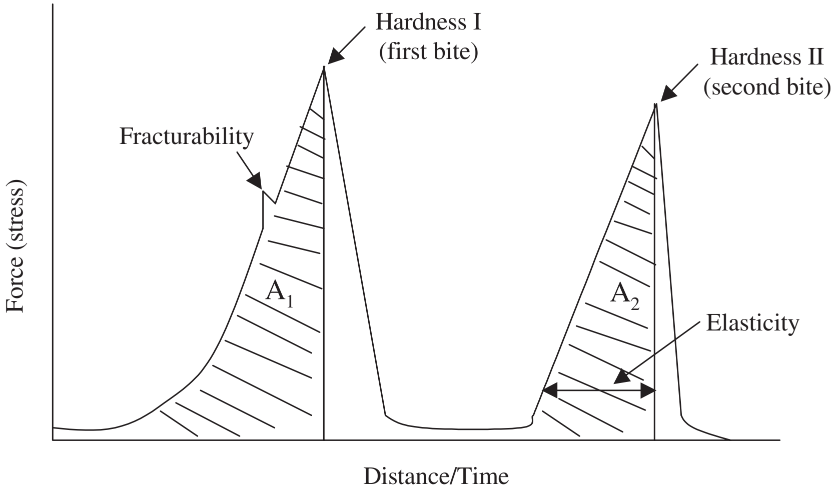
Figure 14.6. *Scanning Electron Microscopy of Meat Batters Containing 2.5% NaCl, Heated to (A,B) 20°C, (C,D) 40°C, (E,F) 55°C and (G,H) 70°C. Micrographs on the Left are at Low Magnification (bar = 15 μm) and on the Right are at Higher Magnification (bar = 3 μm). Showing Spherical Fat Globules within the Protein Matrix. From Barbut et al. (1996). With Permission.*

was increased to 65°C, the strands became thicker (125 vs. 300 nm). Additional heating to 80°C caused a reduction in strand size, but the structure remained ordered. Because Wang and Smith (1992) started monitoring the structure at 55°C, comparison with the structure at a pre-denaturation temperature (e.g., 20°C) was not possible.

Compression and Texture Profile Analyses (TPA)

In this test, a sample is compressed axially between two flat plates [Figure 14.5(c)]. The test can be separated into single compression and double compression. The single-compression test can be done to failure, meaning that the sample is compressed until it breaks. The test can also be done to a pre-fracture point where the deformation is measured. Two extreme food examples would be a hard candy and a marshmallow. In the first case, when force is slowly applied, the sample will hardly deform; however, at a certain point, it will shatter. In the second case, a relatively low force will quickly deform the sample, but the sample can easily recover (highly elastic sample). Meat samples fall in between these two extremes and show moderate elasticity. Voisey et al. (1975) have reported that in a single compression test, the force required to produce failure in a winner-type product was strongly correlated ($R = 0.89$) with sensory chewiness.

The TPA test was developed by a group of scientists at General Foods in the early 1960s. The test is based on a two-cycle compression where a cylindrical sample is compressed to a certain predetermined deformation during the first cycle, and then compressed a second time (Bourne, 1978). The General Foods group has established some parameters that correlate well with sensory data (Figure 14.7). The test is commonly used by food scientists for all sorts of products. However, over the years, different test parameters have been used and made it difficult, if not impossible in some cases, to compare results from different places. Mittal et al. (1992) reviewed test parameters used to evaluate meat samples and indicated that specimen length or height (L) varied from 10–20 mm, diameter (D) from 13–73 mm and D/L ratio from 1–4. The compression ratio varied from 50–85%, and compression speed varied from 5–200 mm/min. The effect of varying D/L, speed and compression rate are shown in Table 14.7. In this case, a commercial-type frankfurter made of beef meat was evaluated; however, the same will be expected for poultry or other meat wieners. The composition of the product was 55.9% water, 28.5% fat, 12.6% protein and 2.9% ash. The results show that a decrease in D/L resulted in a decrease of $H1$, $H2$, cohesiveness and gumminess, while springiness and chewiness increased. Increasing the compression ratio resulted in decreasing springiness, cohesiveness, gumminess and chewiness. According to Peleg (1977), at the same deformation rate, a shorter specimen is actually deformed at a higher strain rate, and therefore, should exhibit higher stress than those of a longer



Cohesiveness = A_2/A_1
Gumminess = Hardness I x Cohesiveness
Chewiness = Gumminess x Elasticity (Springiness)

Figure 14.7. *Generalized Force-Deformation Curve (Two Cycle Compression Test) Used for Texture Profile Analysis. Based on Bourne (1978).*

specimen and the same strain. Thus, TPA parameters are comparable when the tests are performed by a standard procedure. From the results reported in Table 14.3 and results obtained for a ground meat product (salami) and a whole muscle product (corned beef), Mittal et al. (1992) have recommended the use of the following test parameters: $D/L = 1.5$, compression ratio = 75% and rate of compression = 1–2 cm/min. Employing such standard conditions will hopefully prevent problems such as overcompression and allow for a meaningful comparison of results among different laboratories.

Tension

The test is done by pulling apart the sample [Figure 14.5(d)]. This test is often done to determine the strength of sliced, cooked meat products. If a whole muscle product is tested, the orientation of the muscle fibers is very important because muscle fibers pulled 90° to their longitudinal axis will show lower force than fibers pulled along their longitudinal axis.

Results obtained for commercial whole muscle turkey breast meat products showing good and poor slice integrity are shown in Table 14.8. The samples were evaluated after the processor received a complaint from the store indicating a problem with thin slicing (also called shaving). The poor integrity

Table 14.7. Duncan's Test Results for Different Texture Profile Analysis Parameters of Frankfurters. Adapted from Mittal et al. (1992).

	Mean Values (see footnotes)					
	$H1$ (N/cm^2)	$H2$ (N/cm^2)	E (m/cm^2)	COH	GUM (N/cm^2)	CHEW (J/cm^4)
D/L						
2.0	30.11^{a}	23.47^{a}	0.024^{c}	0.405^{a}	11.76^{a}	0.33^{c}
1.5	27.39^{b}	20.40^{b}	0.047^{b}	0.388^{a}	10.25^{b}	0.56^{b}
1.0	24.14^{c}	14.52^{c}	0.084^{a}	0.338^{b}	7.69^{c}	0.77^{a}
Speed (cm/min)						
2.0	29.51^{a}	20.64^{a}	0.053^{a}	0.369^{a}	10.41^{a}	0.58^{a}
1.0	26.81^{b}	20.16^{a}	0.052^{a}	0.369^{a}	10.27^{a}	0.57^{a}
0.5	25.32^{c}	17.59^{b}	0.051^{a}	0.366^{a}	9.02^{b}	0.50^{a}
Compression (%)						
25	22.72^{c}	20.52^{a}	0.070^{a}	0.686^{a}	15.58^{a}	1.05^{a}
50	34.41^{a}	18.51^{b}	0.055^{b}	0.299^{b}	10.54^{b}	0.50^{b}
75	24.50^{b}	19.36^{ab}	0.031^{c}	0.147^{c}	3.59^{c}	0.11^{c}
			Correlation Coefficients			
D/L	0.38**	0.63**	−0.78**	0.11	0.29**	−0.37**
Speed	0.27	0.19	0.02	−0.01	0.09	0.06
Compression	0.11	−0.08	−0.52**	−0.92**	−0.85**	−0.78**

$^{a–c}$Data with the same superscript letter in a column, within a category, are not significantly different at $p > 0.05$ level.

D/L = diameter to length ratio; $H1$ = hardness-1; $H2$ = hardness-2; E = elasticity (springiness); COH = cohesiveness; GUM = gumminess; CHEW = chewiness.

** $p \leq 0.0001$.

Table 14.8. Tension Value (in Newtons) for Commercial Whole Muscle Turkey Breast Roasts Showing Good and Poor Slice Integrity.*

Product	Sample A	Sample B	Sample C	Sample Mean
Good integrity				
1	2.43	2.78	2.51	2.57
2	2.80	2.50	2.30	2.53
3	3.22	2.84	2.71	2.92
Poor integrity				
4	1.64	1.96	1.55	1.71
5	1.15	1.09	1.13	1.12
6	1.77	1.69	1.70	1.72

*3 mm thick slices (20 × 150 mm) pulled apart at 50 mm/min, perpendicular to the muscle fiber orientation.

areas were also examined under the microscope (data not shown here) and reveal poor connective tissue binding the individual muscle fibers.

Torsion

This test is done by twisting the sample that has been carved into a dumbbell shape [Figure 14.5(e)]. The controlled rotation can be done with a viscometer after the sample ends have been glued to plastic disks. The force required to break the sample is measured and is used to calculate true shear strain and shear stress values. The advantage of using this test is that volume changes are minimized and the squeezing out of water, prior to the breakpoint (typically occurring in a compression test), is avoided. The test has been shown to reveal differences in muscle gelation functionality (Table 14.9). The table indicates that shear strain is a measure of protein functionality (i.e., the ability of salt-soluble proteins to form a heat-induced cohesive gel). Shear stress is also dependent on protein functionality, but, in addition, it is strongly influenced by other factors. Overall, shear stress relates to sensory hardness and shear strain to sensory cohesiveness. Figure 14.8 shows these relations in familiar terms. An important implication of the data presented in Table 14.9 is that it is more difficult to modify sensory cohesiveness by addition of ingredients than it is to modify sensory hardness of meat gels. Montejano et al. (1985) compared torsion and TPA results with sensory results for eight protein gels (made from low-fat beef, pork, turkey and egg whites). Shear strains at rupture ranged from 1.2–2.8 m/m. TPA cohesiveness correlated strongly with six of their sensory notes (springiness, hardness, cohesiveness, denseness, chewiness, gel persistence). Furthermore, these two instrumental parameters correlated strongly ($R = 0.83$), as did the six sensory notes. Stress

Table 14.9. Degree of Influence of Different Factors on Failure Stress and Strain of Processed Muscle Foods. From Hamann (1988). With Permission.

Factor	Shear Stress	Shear Strain
Protein functionality	S*	S
Protein concentration	S	W
Filler ingredients	S	W
Thermal process	S–M	W

*S = strong, M = moderate, W = weak.

and TPA hardness correlated strongly ($R = 0.94$), but did not correlate as strongly with the sensory notes as did the parameters based on deformation to failure.

Scanning Rigidity Monitoring

The test is used to continuously monitor a process such as gelation during heating. The small-strain gel rigidity measurements (see example in Figure 9.5) have been shown in several studies not to correlate well with sensory texture or rupture strength. However, the information is valuable in monitoring physical changes in the gel that relate to molecular changes (Hamann, 1988). The changes in rigidity provide circumstantial evidence of the changes taking place during gelation (structure-building phase). The changes are related to protein unfolding, bonding of molecules and interactions with other non-meat

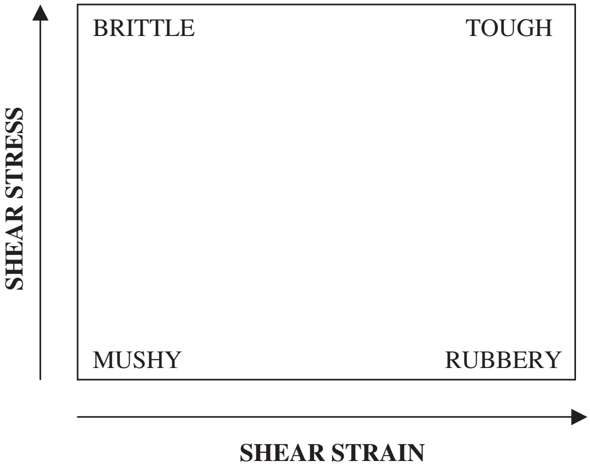


Figure 14.8. *Use of Familiar Terms to Show the Relationships Between Shear Stress and Shear Strain. Based on Information from Hamann (1988).*

components such as starch and carrageenan. One of the first laboratory devices employed a microscope coverslip glass submerged in a protein solution that was moved up and down at a very slow rate and short distance while the sample was heated. The resistance to movement was recorded and plotted against temperature. Results of such a test are shown in Figure 9.4, where different concentrations of actin and myosin were heated together. The data provided valuable information on gelation temperatures, effect of the ratio of myosin:actin on gel structure formation and magnitude of the protein-protein interactions. Today, various commercial controlled stress/strain rheometers can be purchased and attached to a computer for precise movement control, temperature changes and easy calculations. An example of results, obtained by a commercial rheometer, showing the effect of pH on myosin gelation is shown in Figure 9.6. The effect of phosphate addition to low-salt poultry meat batter is shown in Figure 9.5.

WATER-HOLDING CAPACITY (WHC)

Most poultry products contain 60–80% moisture that is held by the protein matrix. The amount of protein is usually around 10–20% of the product. In certain countries, such as Canada, a minimum of 11% protein is required to be present in various processed meat products, where 9.5% should be meat proteins; otherwise, words like “imitation” should be included in the product’s name. The other major component is fat, which usually ranges between 5–35%. However, fat does not contribute to water-holding capacity, and sometimes high fat products show poor moisture holding, as will be discussed later. Therefore, obtaining protein with good functional properties is of paramount importance. The quality of the proteins, in terms of water-holding capacity, is influenced by the type of muscle, pre- and post-rigor conditions (DFD and PSE meat; see Chapter 2), and processing treatments such as freezing (i.e., freezing would usually have a negative effect on water-holding capacity; see Chapter 7).

Determining the water-holding capacity is important for fresh meat cuts sold directly to the consumer and for further processed products prepared by the industry. In both cases, high yield and low cooking losses are desired. Consumers shy away from packages of fresh meat showing free fluid surrounding the cuts. This is also true for cooked products, such as frankfurters, showing exudate in the package.

Over the years, different methods have been suggested to estimate the water-holding capacity of various meat and non-meat protein systems (Hermansson, 1986; Trout, 1988; Barbut, 1996). As indicated in the introduction, the existence of different methods and the use of different test conditions have made it difficult to compare results from different research groups. In this section, the major methods used for poultry meat will be reviewed, and a few will be highlighted as potential standard methods for different applications (e.g., fresh meat, processed products).

Scientific Basis

Over the years, researchers measuring WHC have used terms such as water binding, water retention, hydration capacity, water absorption, suction potential and swelling to describe the phenomenon of WHC. The specific molecular structure of a protein and its conformation have a significant effect on WHC, as has been described in various reviews (Mohsenin, 1986; Kinsella et al., 1989). For practical reasons, water held within a protein structure (e.g., fresh muscle, comminuted meat product) can be divided into three major categories.

- Bound water—includes water directly attached to the protein molecule that is no longer available as a solvent. In muscle food, it usually amounts to 4–10 g water/100 g of the meat protein. In this case, the polar water molecules react with the charged side chains of the amino acids.
- Immobilized water—represents water molecules attached (commonly by hydrogen bonds) to the bound water in bonds that become successively weaker as the distance from the protein charged groups is increased. In muscle food, it usually amounts to 20–60 g/100 g protein.
- Free water—is mainly held by surface forces. This category is of major importance in further meat processing and usually represents 300–600 g/100 g protein. This water can be relatively easily squeezed out of the meat, and the processor's goal is to keep it in the product. In other instances, where the processor adds extra moisture by injection/marination (see Chapter 9), the increase is mainly to the free water category.

A more detailed description of the types of water found in a food protein system was provided by Kinsella et al. (1989). They distinguished between six basic categories: structural water that is tightly bound to the protein molecules and unavailable for chemical reaction, hydrophobic hydration water found around apolar residues of amino acids, monolayer water that is the first layer of water absorbed to the protein groups and may be available for some reactions, unfreezable water consisting of water that does not freeze at the first sharp transition temperature, capillary water that is held by surface tension forces and hydrodynamic hydration water that loosely surrounds the proteins. The amount of water and degree of binding of each of these categories are affected by factors such as pH, protein type and concentration, number of exposed charged groups, salt and temperature.

The effect of pH is one of the most important factors that can be controlled by the processor and, therefore, will be explained here in detail.

pH is a shorthand way of designating the hydrogen ion activity of a solution. By definition, pH is the negative logarithm of the hydrogen ion activity. Similarly, pOH is the negative logarithm of the hydroxyl ion activity.

$$\text{pH} = -\log\,[\text{H}^+] = \log \frac{1}{[\text{H}^+]}$$

In dilute solutions of acids and bases, and in pure water, the activities of H^+ and OH^- may be considered to be the same as their concentrations.

In all aqueous solutions, the equilibrium for the ionization of water must be satisfied, that is:

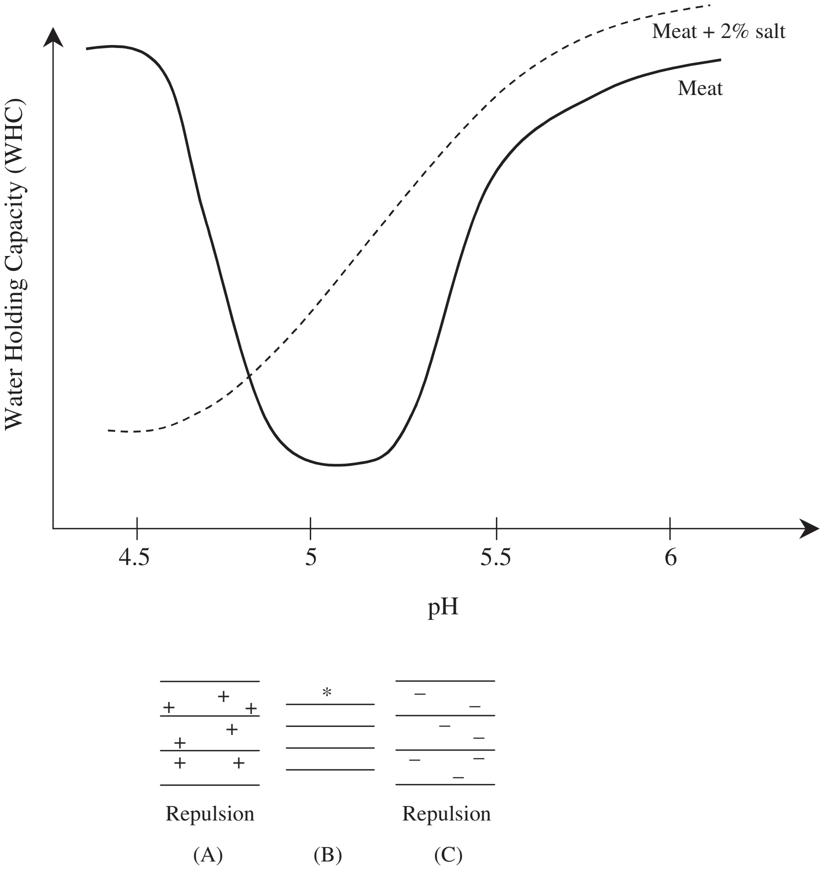
$$[\text{H}^+]\,[\text{OH}^-] = K_w = 10^{-14}$$

Thus, if $[H^+]$ is known, we can easily calculate $[OH^-]$.

A protein molecule (e.g., actin, myosin) consists of a chain of individual amino acids attached to each other by peptide bonds. This consists of the *primary* structure that refers to the sequential order of amino acids in a protein. *Secondary* and *tertiary* structures relate to the three-dimensional organization for the polypeptide chain. *Quaternary* structure refers to the geometric arrangement among various polypeptide chains, as these chains linked by bonds that, in most cases, are not covalent. The side chains of the amino acids are “sticking out” from the main strand of the protein molecule. The side chains can be neutral or positively or negatively charged depending on the amino acid and the pH of the environment. After slaughter, the pH of the muscle drops (Figure 2.18) due to the accumulation of lactic acid in the muscle. The pH drop results in an overall reduction of reactive charged groups on the protein molecules. These reactive groups are the ones available for water binding. The shift in pH causes a reduction in WHC (Figure 14.9) that can be explained as the result of three main factors (Hedrick et al., 1994):

a. *Net charge effect*—refers to the amount of charged groups on the protein molecules that are available for water binding. pH reduction in postmortem meat occurs due to lactic acid accumulation resulting in the pH approaching the isoelectric point of the muscle proteins (pH at which the number of negatively and positively charged groups is equal). As a result, the side chain groups will have fewer groups available for water attachment (also known as the net charge effect). At the normal body pH (around 7.0), more water can be bound to the muscle proteins compared to the post-rigor meat at a pH of about 5.6 (Figure 14.9). This means that at a higher pH, the net charge is greater and more bound or immobilized water can be attached to the proteins.

b. *Steric effect*—refers to the repulsion phenomenon seen when side chains are charged with a similar charge. Basically, similarly charged groups will



* Isoelectric point

Figure 14.9. *Effect of pH on the Amount of Immobilized Water Present in Meat due to Its Impact on the Distribution of Charged Groups on the Myofilaments and the Amount of Space Between Them. (A) Excess Positive Charges on the Filaments. (B) Balance of Positive and Negative Charges. (C) Excess Negative Charges on the Filaments. Adapted from Price and Schweigert (1987).*

repel each other. This, in turn, is beneficial to the meat processor because larger spaces are created and made available for water molecules to reside. This can happen on both sides of the isoelectric point, where a high proportion of negatively or positively charged groups will result in more repulsion. Because the pH of the postmortem meat is usually approaching the isoelectric point, the WHC is reduced. Ingredients such as alkaline phosphates and acids are sometimes used to shift the pH, and hence, increase WHC.

c. *Ion exchange*—takes place during the meat aging process (after rigor mortis has been completed), where enzymatic degradation of cellular structure results in redistribution of ions. Replacing some of the divalent ions, such as calcium, with monovalent ions, such as sodium, helps to free charged protein side groups and increase WHC. The calcium ion is mentioned here because it is released during the postmortem process and is capable of attaching two negatively charged side groups and, by that, neutralizing two negatively charged groups. Once replaced by monovalent ions, the proteins can bind more water.

The addition of sodium chloride to a meat system is known to significantly improve the WHC. This can be seen in Figure 14.9, where the WHC curve is shifted to the left. This is the result of solubilizing the myofibrillar proteins (also called the salt-soluble fraction; Chapter 2) and of adding more negative chloride ions to the system. There is an optimal salt level that could be used to increase WHC or, in other words, decrease shrink (Figure 9.1). The figure shows that increasing the salt concentration from 0–3% has a dramatic effect on reducing shrink. However, above 5%, the reverse is seen due to the so-called "salting-out" effect. At high salt concentration, the proteins will aggregate and, by doing so, they will fold, and their protein-charged side groups will not be available for water binding (i.e., side groups are "buried" inside the protein structure).

The major methods used to estimate WHC in fresh meat and meat products include the following:

- applying pressure (mild to severe; by compression or centrifugation)
- observing the sample behavior during normal processing (e.g., cooking)
- studying the microstructure of the meat product
- using special instruments such as nuclear magnetic resonance (NMR) to study the state and position of the water molecules
- using optical sensors

The following is a brief discussion regarding the different common approaches used by researchers and industry personnel to evaluate WHC.

Pressure Application

According to this approach, an external force is applied, commonly by a hydraulic press or a centrifuge, to extract various degrees of water from the sample.

Press methods have been used to evaluate the amount of "squeezable" water. The sample is compressed between two parallel plates using a hydraulic press or a texture analyzer. The released moisture is collected on a preweighed filter paper (Trout, 1988; Zhang et al., 1993). During the test, the sample is usually compressed into a thin film and most/all of the free water is squeezed out. Over the years, a wide range of conditions have been reported for meat sample evaluation. They range from a force of 0.01–44 kN, sample size of 0.3–1.5 g, temperature of 4–23°C and compression time from 1–20 minutes. In addition, different filter papers have been used. Zhang et al. (1993) evaluated test conditions such as applied force, sample size, compression time and salt in ground beef meat samples. After analyzing the data, they proposed the following conditions: sample size of 1 g, compression force of 20 kN, compression time of 2 minutes, salt concentration between 0–2% (i.e., salt level is commonly used as part of the experimental treatment).

High-speed centrifugation has been applied to samples placed in test tubes. Over the years, various test conditions have been reported for different foods. In the case of meat samples, reported conditions varied in sample size (1.5–20 g) and force applied (1,500–190,000 g). This represents a very large variation (13-fold in terms of sample size and 127-fold in g force) that does not allow proper comparison of the results (Zhang et al., 1995). The data in Table 14.10 are used to illustrate this point. In the test, low, medium and high g forces were

Table 14.10. Centrifugal Method—Effect of g Force, Time, Temperature and Salt Level on Water-Holding Capacity (WHC) of Lean Meat. Adapted From Zhang et al. (1995).

	Mean Value of WHC			
		Centrifugal Force (g)		
Test Conditions	Overall	959	8,630	34,500
Test time (min)				
7.5	4.0^{a}	23.7^{a}	4.1^{a}	-15.7^{a}
15.0	1.1^{b}	25.0^{ab}	-3.7^{b}	-17.9^{b}
22.5	1.2^{b}	27.0^{b}	-4.9^{b}	-18.5^{b}
Test temperature (˚C)				
2	6.5^{a}	28.3^{a}	6.0^{a}	-14.9^{a}
10	1.8^{b}	26.6^{a}	-3.3^{b}	-18.0^{b}
20	-1.9^{c}	20.7^{b}	-7.1^{c}	-19.2^{c}
Salt concentration (M)				
0.0	-2.2^{c}	19.3^{c}	-4.7^{c}	-21.3^{c}
0.3	1.9^{b}	25.3^{b}	1.9^{b}	-17.6^{b}
0.6	6.6^{a}	31.0^{a}	2.1^{a}	-13.2^{a}
Centrifugal force (g)				
959	25.2^{a}	—	—	—
8,630	-1.5^{b}	—	—	—
34,500	-17.4^{c}	—	—	—

Mean values (n = 5) followed by the same superscript letter in a column are not significantly different at the 95% level.

used at three different times, temperatures and salt levels. The test was based on the fairly common test procedure reported by Wardlaw et al. (1973) that has been used in poultry meat research by quite a few investigators. According to this test, 16 ml of a salt solution (0.6 M) are added to a meat sample (10 g) and incubated for 30 minutes at a refrigerated temperature prior to centrifugation. The WHC is expressed as follows:

$$\left(\frac{\text{Solution added to sample} - \text{Solution decanted after centrifugation}}{\text{Meat sample mass}}\right) \times 100$$

The reason for adding moisture is to evaluate the potential ability of the meat to hold extra moisture, which is commonly done on an industrial scale (e.g., injection; see Chapter 9). At a high g force, water was expelled from the sample (Table 14.10; shown as a negative value), while at low g force, it was retained. Based on statistical analysis, the following conditions were suggested for evaluating a fresh meat sample: 8,630 g for 7.5 minutes at 20°C at all the salt concentrations tested (0–2.25%; corresponding to 0–0.6 M NaCl in the salt solution added to the meat). It is important to note that as was shown in the data presented here and by other researchers, the increase in g force does not cause a linear increase in the values obtained, and the relationship between the size of the test tube and the sample is critical because a sample that is in tight contact with the test tube's wall will not allow all the water to be drained. Other studies of heat-gelled plasma proteins (i.e., cooked sample) used to investigate the effect of g force, and separation of the exudated water, have shown that using a net (or a basket) to separate the sample from the bottom can affect the results (Table 14.11). The reason for this is that some of the extracted water can be reabsorbed if the sample is placed at the bottom of the test tube. This is clearly illustrated when comparing a 1 g sample centrifuged at 5,090 g in a regular test tube and a similar sample placed on a net and centrifuged at 465 g (Table 14.11).

In case of a cooked protein gel, the state of the sample after applying a high centrifugation force has been investigated by Hermansson and Lucisano (1982) and Kocher and Foegeding (1993). They showed that a permanent sample deformation indicates structural breakdown. Therefore, they recommended using low g force conditions that will not damage the actual cooked gel structure.

Low-speed centrifugation refers to 100–1,000 g applied to cooked/gelled protein samples (Wierbicki et al., 1957; Hermansson, 1986; Barbut, 1996). The main advantage is that sample deformation is minimal and no or minimal structural damage occurs. In this test, a small sample is centrifuged at about 750 g for 10 minutes (Table 14.11). The sample is placed in a basket or on top of a screen to prevent reabsorption of the released liquid. This is a very important measure, because the food structure can reabsorb some of the

Table 14.11. Effect of Experimental Conditions on Moisture Loss (%) Values of 5% Plasma Protein at pH 9.0 Heated at 82°C. Adapted from Hermansson and Lucisano (1982).

	Sample Weight (g)		
Force (g)	1	2	5
High speed		(small tube—10 mm diameter)	
5,090	6.9	3.8	1.1
9,750	13.1	6.6	2.0
30,000	41.1	38.3	36.9
High speed		(large tube—27 mm diameter)	
5,090	—	—	20.0
9,750	—	—	28.1
30,000	—	—	51.1
Net test			
465	41	20	15
790	41	18	19
1,045	42	20	15
1,290	41	22	20

—: Not determined.

moisture during the slowdown of the centrifugation process and the time until decanting the liquid. As indicated above, the data in Table 14.11 illustrate that the absence of a mechanism to prevent reabsorption results in different results than in the presence of a basket/screen. Based on the above-mentioned references, the suggested test conditions for a proposed standardized test are force of 750 g and centrifugation of 10 minutes at 20°C (Figure 14.10).

Observing Sample Behavior

Observing sample behavior is a common method used by industry to monitor cooking losses from a given formulation. The procedure usually duplicates steps used on a production line, but on a smaller scale, with a test sample of 0.1–1.0 kg. The yield can be calculated by weighing the product before and after cooking or by collecting the liquids (water, fat) if the test is performed in a closed system (plastic bag/casings or a test tube). The latter allows the binding of water and fat to be studied separately and ingredients that would selectively enhance binding of one of the components to be examined.

Study of Microstructure

As indicated in the previous section, the structure of a gel can be assessed by microscopical examination. The structure can be viewed by low magnification

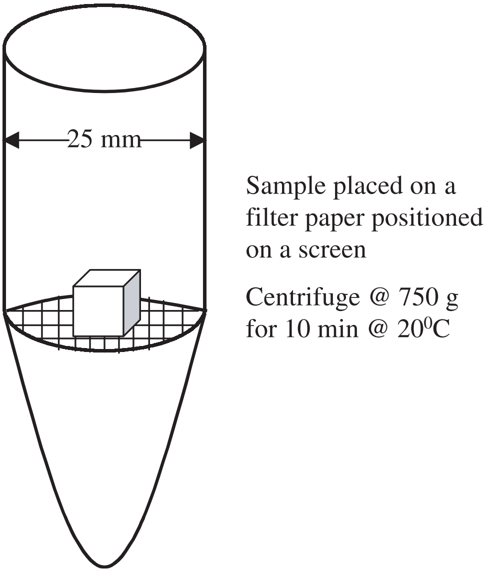

25 mm
Sample placed on a filter paper positioned on a screen
Centrifuge @ 750 g for 10 min @ 20⁰C

Figure 14.10. *A Procedure for the Net Test.*

light microscopy or by high magnification (scanning or transmission) electron microscopy, which can reveal much more detail (Figure 14.6). Studying the relationship between structure and functionality is a growing area of research and helps to provide food scientists with a better understanding of the factors affecting gelation and water holding. Proteins can form different gels depending on concentration, pH, ionic strength, temperature, etc. In general, protein gels show two distinct structures. The first category is the fine-stranded gels, produced by association of small-diameter molecules to form an ordered network. The second category is aggregated gels that are comprised of relatively large particles bound to one another to form a gel network. There are also mixed gels and/or gels showing different degrees of transition between the first and second categories.

Information obtained by microscopy can be used to show how microstructure affects WHC. Pore size in the range of 0.1 to 2.0 µm appears to be of great importance in food systems. Capillary forces can exhibit a high force at a small-pore diameter. Calculating the height of a water column that can be drawn by capillary forces (due to surface tension) shows that a 0.1 µm radius capillary draws water up to 150 m, 1.0 µm to 15 m, 10 µm to 1.5 m and 100 µm to 0.15 m. The corresponding water activities will be 0.99, 0.999, 0.9999 and 0.99999, respectively (Hermansson, 1986).

Changing the pH or salt level in a meat batter can result in the formation of a finer protein structure. Wang and Smith (1992) showed that chicken breast salt-soluble proteins (0.6 M NaCl) formed a finer structure at pH 6.5 and 7.5 than at pH 4.5; the latter showed large aggregates. Such a change will also affect the WHC. In finely comminuted meat batters, Gordon and Barbut (1992) showed that adding urea caused a reduction in pore size, as compared to a control (2.5% salt) and, hence, resulted in a much higher WHC (0.4 vs. 4.8%, respectively). Overall, the relationship between a protein gel structure (i.e., pore size) and WHC still requires more work to better understand the combined forces governing WHC.

Special Instruments (NMR, DSC)

Special instruments such as nuclear magnetic resonance (NMR) and differential scanning calorimetry (DSC) can be used to indirectly measure the degree of WHC in various foods. These instruments can provide precise information on water molecule relaxation time (by NMR) and the degree of hydration and/or amount of freezable water in a protein system (by DSC). Overall, such equipment is much more expensive than that used for the methods described earlier and requires more extensive technical knowledge both to operate and to interpret the results. However, fundamental information on the relationship between proteins and WHC can be obtained.

NMR spectroscopy measures water binding indirectly by scanning a small homogeneous sample (usually 1–5 g placed in an NMR tube) several hundred times to produce a representative value for the relaxation times of the water molecules within the sample. The values indicate the times required for the magnetic nuclei of the water molecules to return to their original energy level after being excited to a higher energy level (by high-frequency radio waves in the presence of a magnetic field). The three nuclei with magnetic moments that can be used in an NMR study of water are the proton, the deutron and oxygen-17; the last two are most commonly used. After excitation, the nuclei show two relaxation times (T_1 and T_2). These represent the times required for the longitudinal (rotational) and transfer (gyrational) motions of the nuclei to return to normal. Usually, the T_2 values are used to determine WHC in food systems such as muscle because they show greater changes. In pure water, T_2 values are in the order of 1–2 seconds, and when compounds such as proteins are present, the time is reduced by a factor of 10–150. This is because proteins can absorb some of the energy from the water, resulting in a faster return to the original low-energy state. In a muscle system, a large portion of the water is held in pores; therefore, it has a shorter distance to diffuse to the water-protein interface than in a pure water system. As a result, the water in the pores shows a much lower T_2 value. For more detailed information on the fundamentals of NMR, the reader is referred to McCarthy (1994).

Optical Sensors

One example in the meat industry where color measurements are commonly used to sort out the pale, soft, exudative (PSE) meat is in the pork industry. In the poultry industry, only a few processors are starting to use the procedure (see Chapter 6). The relationship between color and WHC in meat is very complex and not fully understood. However, for practical application, it was found that the lightness value can be used to predict the PSE condition (Bendall and Swatland, 1989). Development of this particular optical method will be used here to illustrate some of the problems encountered during the implementation of the method. Overall, the evaluation of meat reflectance, used to predict WHC, correlates pretty well with the violet and red light regions (Swatland, 1995). However, in the past, various researchers have used the conventional CIE L^*, a^* and b^* system (see Chapter 13) and did not obtain very good results. The CIE system puts much more emphasis on green light, because this is the region where the human eye is most sensitive. Equipment that does not concentrate on the green region usually shows much better correlations and is preferred to assess WHC. Another point that one should be aware of is the determination of the "type" of water measured in the meat. Bendall and Swatland (1989) discussed, in great detail, the effect of measuring water coming from the myofibrial spaces compared with water coming from the inter-fiber and inter-fasciular spaces, as well as the relationship between WHC and pH. Depending on the "type" of water, the curve can either be linear (increasing from pH 5–7), or stepwise with a change at around pH 6. In order to compare results, they summarized data from different publications and showed that the physical location of the water determines the apparent behavior of the curve. Therefore, when optical measurement is used, one should be careful in understanding the origin of the water. Overall, water within the myofibrial spaces is highly pH-dependent, whereas inter-fibrillar water is much more dependent on capillary forces. Swatland and Barbut (1995) reported that near-infrared (NIR) birefringence was correlated with WHC of raw turkey breast meat samples ($r = 0.85$, $P < 0.0005$) and with fluid losses during cooking ($r = -0.82$, $p < 0.005$). The NIR birefringence probe was almost as useful as pH and better than a visible colorimeter paleness measurement for predicting WHC and cooking losses of the turkey meat samples. Two of the main advantages of using an optical probe are the elimination of a glass pH probe that might shatter in the product and the shorter response time of an optical probe.

Optical methods can also be used to monitor a specific component important in WHC. For example, collagen content in meat batters can be monitored with a quartz probe that evaluate fluorescence intensity. Collagen (part of the connective tissue of the muscle) can be detrimental to WHC if present at high levels, because its conversion to gelatin during cooking can result in cooking losses. Therefore, a high collagen content determination (based on a characteristic fluorescence pattern) has successfully been used to predict cooking losses ($r = 0.99$, $P < 0.005$) and WHC (Swatland and Barbut, 1991). When the latter was compared to a common centrifugation method (i.e., raw meat mixed with salt and centrifuged at 7,000 g; Wardlaw et al., 1973), a good correlation ($r = -0.92$, $P < 0.005$) was obtained.

The actual relationships between collagen content (i.e., skin content) in the meat and the cooking losses of the water and fat components are shown in Figure 14.11(a). Figure 14.11(b) shows the actual correlations, obtained at different wavelengths, of the different parameters measured. The figure illustrates the way such optical sensors are being developed and where the best one or two wavelength(s) are selected to predict a certain characteristic. Employing a sensor based on one or two wavelengths is more economical, fast

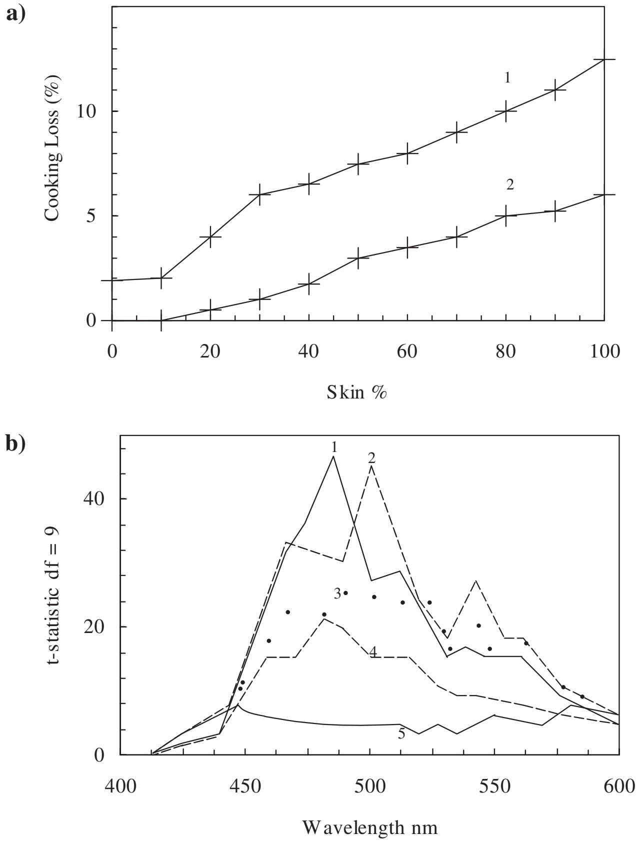


Figure 14.11. *Use of a Quartz-Glass Probe to Measure Poultry Skin Content and Processing Characteristics. (a) Effect of Percent Skin on Total Cooking Loss (Line 1) and the Lipid Fraction of the Cooking Loss (Line 2). (b) Spectral Distribution of the Absolute Values of t-Statistics of the Correlations of Fluorescence with Percent Skin (Line 1, Solid), Gel Strength (Line 2, Bars), Fluid Cooking Loss (Line 3, Dots), Lipid Cooking Loss (Line 4, Bars) and Centrifugation Fluid Loss (Line 5, Solid). From Swatland and Barbut (1991). With Permission.*

and easy to operate. Alternatively, if a photodiode array is used, examining one or two wavelength(s) is also advantageous. Overall, there are many opportunities in the food industry for employing fast-responding sensors and computers to reduce production costs and optimize product quality (Swatland, 1995). The development of new optical sensors for monitoring WHC could save money by allowing fast feedback control of meat batter composition, etc.

FAT-HOLDING CAPACITY

The ability of a further processed product, such as a frankfurter, that contains up to 30% fat, to retain its fat is of great importance to the meat industry. Keeping the fat within the product represents a challenge to the processor, especially during the cooking phase when the fat is converted to liquid (i.e., at a temperature >50°C). The liquid fat can flow out of the product if not properly held. Sometimes this is desirable, as is the case in roasting a whole chicken in an oven, where the subcutaneous and abdominal fat drips out of the chicken. However, in products such as bologna and salami, fat losses would leave voids in the product and adversely affect the texture and mouthfeel. Therefore, methods to predict fat-holding capacity in processed products have been developed. In some cases, the fat-holding parameters are used as descriptors in Least Cost Formulation programs (see Chapter 9). In such programs, different raw materials are assigned numerical values indicating their functional properties, such as relative fat-holding capacity. The values are used to attain certain characteristics in the finished product, while different meats can be substituted in a formulation.

Some of the methods used to determine fat holding are similar to WHC methods and involve the following:

- exposing the sample to pressure (mild to severe compression or centrifugation)
- observing the sample's behavior during normal processing conditions (e.g., cooking)
- studying the microstructure
- measuring emulsification capacity to determine maximum oil load
- extraction of fat with a solvent, such as hexane
- optical methods.

The fat in a meat product is held either within fat cells (i.e., cellular structures used in the body for fat deposits) or as fat droplets that have lost the cellular "envelope." The latter is the case in emulsified meat products where the fat tissue is finally chopped in a high-speed, silent cutter or an emulsion mill (see Chapter 8). In such a case, the interactions between the protein matrix and fat are very important because the protein serves as an emulsifier (i.e., having hydrophilic and hydrophobic sites) that creates an intermediate between the aqueous and fat phases.

Pressure Application

As with methods described for WHC, high- and low-speed centrifugation have been used to study fat binding in meat products. The net-test has been used to evaluate fat holding in hamburger-type products (Figure 14.12). Fat losses were minor in low-fat hamburgers and increased linearly with fat content ($r = 0.98$). The corresponding net-test showed a linear increase ($r = 0.88$), and fat losses were significantly higher than for the frying test. The authors suggested that the higher values observed were due to the centrifugal force applied after cooking. They used a force of 500 g to centrifuge 10 g samples that were cooked in test tubes (77°C for 35 minutes). The authors also suggested that the longer cooking time used for the net-test allowed fat to coalesce more and, therefore, separate more easily from the product. In any case, the net-test is useful for predicting fat holding in such a ground meat product.

High centrifugation force should be used when evaluating raw meat products, because low force will not remove any fat from the product. Such a high g force test is not very popular in the meat industry but has been used in research for determining the effect of different chloride salts on meat batter stability. Gordon and Barbut (1989) used 18,000 g to separate some of the fat from meat batters prepared with sodium chloride, magnesium chloride and calcium chloride. The test was useful in showing a significantly higher fat release from the two divalent salt treatments compared to the monovalent salt. In addition, it revealed a significant difference between the two divalent salts in their influence on fat holding in raw meat batters. In the cooked meat products, both salts showed a detrimental effect on fat-holding capacity that results in almost total fat loss from the meat batters. That is one of the main reasons why calcium-reduced, non-fat dry milk should be used in emulsion-type meat products as opposed to regular non-fat dry milk powder.

Cooking Test

Observing a sample during a normal cooking process and monitoring the amount of fat (and/or water) lost are very common and have been reported in numerous research and industry reports. Such an observation can indicate advantages/disadvantages of using certain meats, employing certain processes and using different non-meat ingredients. The test is easy to perform and does not require sophisticated equipment. However, it should be realized that this test is not usually designed to check the upper limit of fat-holding capacity. This can be a problem if variations in the standard meat mixtures (e.g., higher

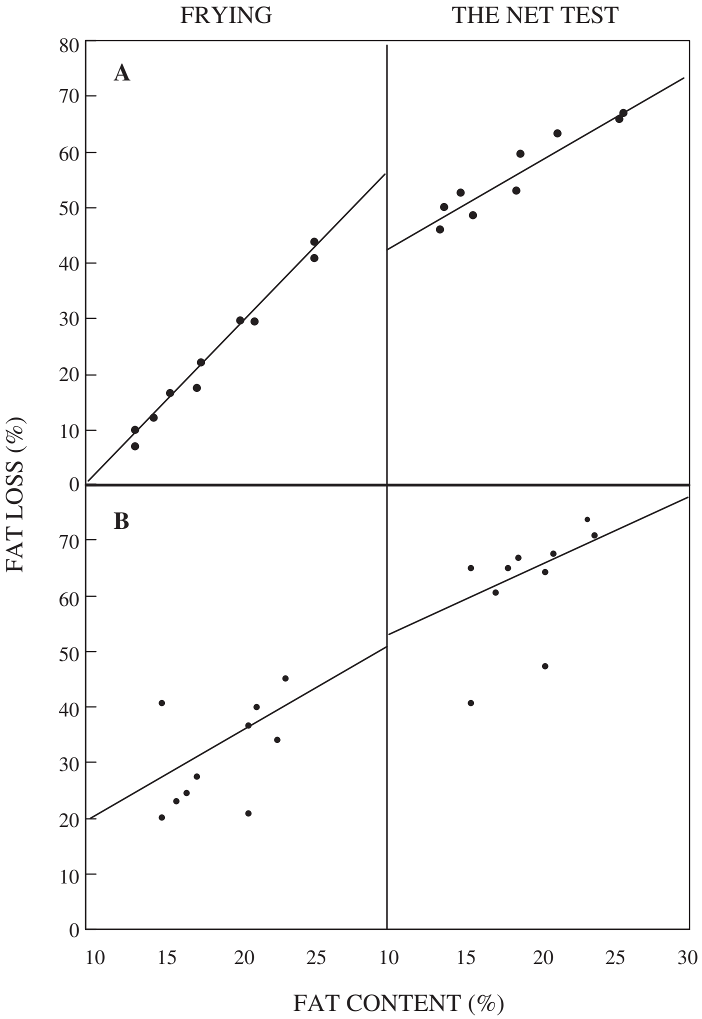


Figure 14.12. *Fat Loss (%) on Frying (Left) and as Determined Using the Net Test (Right) as a Function of Fat Content (%) for Hamburger Patties with (A) Adipose Tissue and (B) Rendered Fat. Redrawn from Olsson and Tornberg (1991).*

levels of connective tissue in some batches) and/or processing conditions are expected.

As with WHC, the procedure duplicates the steps used on a production line, but on a smaller scale, with a test sample of 100–1,000 g. The test was used to study the effect of fat level on fat retention (Figure 14.12), the effect of lipid composition on fat retention, etc. Whiting (1987) used the test to study the effect of a broad spectrum of chemical compounds (alcohols, monoglycerides, nonionic detergents, chelating agents, etc.) on fat holding in a muscle protein system. He showed that cations from groups IA and IIA of the periodic table equaled or surpassed the stability obtained in meat batters prepared with sodium chloride. The inclusion of cations such as zinc greatly reduced fat holding. Nonionic detergents, alcohols and monoglycerides were detrimental for fat holding and water holding. Other compounds such as urea, which stabilizes hydrophobic and peptide groups, helped to improve fat holding. The cooking test was also beneficial, in his study, to provide information about the mechanisms associated with fat binding. In Figure 14.12, the cooking test (frying in this case) was used to find more practical applications concerning the relationship between fat level and fat retention. This relationship is important to processors, restaurant operators and consumers in terms of yield and product acceptability. Overall, fat losses were minimal at low fat content when regular fat was used. When rendered fat (heated to 80°C for 30 minutes and then filtered to remove cell wall material) was used, fat losses even at the low fat level were much higher than when regular adipose tissue was used. The reason for this was the absence of cell wall structure (connective tissue matrix) to hold the fat in place during frying. Another advantage of this test is that a relatively large representative sample can be used.

Study of Microstructure

As indicated earlier, this approach is used to evaluate the structure of a product and to study the relationship between microstructure and fat/water holding. Overall, the protein gel matrix has an open structure (Figure 14.6) with fat globules embedded within the matrix (see fat globules in the figure). Usually, there is a thin protein coat around the fat globule that serves as an intermediate layer separating the fat and the aqueous phase (i.e., an emulsifying agent). Examining this interaction is important in understanding some of the mechanisms responsible for fat holding. The products evaluated in Figure 14.12 were also examined under a light microscope. The authors showed that when regular fat trimmings were used, intact fat cells were dispersed within the protein matrix. However, rendered fat resulted in large fat pools, and only a few cell walls (stained with aniline blue) still existed to a certain degree. This, as evaluated by the frying and net tests, was an important factor in the degree of fat holding. In the rendered fat treatments, hardly any connective tissue around fat cells was seen, and resulted in higher fat losses, compared to using regular fat trimmings. Besides being able to assess fat losses from the sample, microscopical studies can be used to learn about the reason(s) for fat separation and to assist in suggesting ways to improve the product. Micrographs collected can also be evaluated by image analysis systems that automatically measure and calculate fat globule size, area and distribution (Swatland, 1995).

In finely comminuted meat products, the characteristics of the protein matrix can be very important for proper fat holding. The addition of ingredients such as polyphosphate, which also serves as an emulsifier, can greatly enhance fat holding (Gordon and Barbut, 1989). The size of the pores within the protein matrix, as well as the extent of interfacial protein film, determine the amount of fat that can be held within the product. This type of work can only be done at high magnification where scanning/ transmission electron microscopes are used.

Measuring Emulsification Capacity

These tests are done by overloading the system with liquid oil (usually vegetable oil) and determining the maximum fat emulsification point. The tests have been used by numerous researchers and have also been employed in the development of a numerical system for scoring meat for the Least Cost Formulation program (see Chapter 9). During the test, a high-speed homogenizer (or sometimes a food processor) is used to emulsify the oil, which is added slowly, at a constant rate, to a known protein solution. The oil is gradually emulsified until it overloads the system and reaches a point known as "breakdown" when the oil and protein phases separate. This separation can be seen by the abrupt change in viscosity or by a change in the sound of the mixer (Maurer et al., 1969). Changes in electrical conductivity can also be monitored because the continuous fat phase has a much higher resistance to electrical conductivity after the "breakdown" point has been reached. The test is usually carried out at room temperature, and a vegetable oil such as cottonseed oil is slowly added at a rate of about 1 ml/sec. Maurer et al. (1969) used the test to characterize proteins from chicken breast muscle. They showed that salt-soluble proteins had a higher emulsifying capacity compared to salt-soluble proteins from which salt was removed by dialysis prior to the test or the same proteins to which salt was added again after dialysis.

Solvent Extraction

This test has been used by some researchers to extract unstable fat from meat products. The unstable fat has been referred to as fat that is not surrounded by cellular membrane structure or fat that is not properly emulsified and surrounded by an interfacial protein film. Tornberg et al. (1989) used hexane to extract unstable fat from hamburger-type products produced with 20% fat. The extraction results were similar to the net-test results obtained by centrifugation. The authors suggested that most of the unstable fat could be released by either a mild centrifugation force or by the hexane extraction method. Overall, this test is not widely reported in the literature, but it is an empirical method capable of measuring coalescence stability over a wide range.

Optical Methods

Spectrophotometry is not commonly used to assess fat binding in food products, but it is relatively widely used to monitor the absolute fat content in foods by using infrared. However, the drive to develop rapid methods to assess conditions of food processing lines has sparked interest in such methods. One example is the development of a fiber-optic probe to predict lipid content and processing losses of comminuted meat batters. A bifurcated light guide was developed to measure reflectance of different lean beef and fat mixtures (Swatland and Barbut, 1990). In the development work, light reflectance in the range of 400–1,000 nm was investigated. Reflectance at 1,000 nm correlated best with lipid content of the meat/fat mixtures ($r = 0.99$, $P < 0.005$). At 930 nm, centrifugation fluid loss was significantly correlated ($r = 0.77$, $P < 0.005$) with fat content of the mixtures. Such a probe can be calibrated against a reference and provide rapid response to control composition of meat slurries in a continuous processing line. The use of a probe to examine skin content and to predict fat losses from a meat batter is shown in Figure 14.11. As described in the WHC section, the advantage of a light-measuring device/probe is its fast response, convenient use for on-line measurements and relatively simple operation.

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CHAPTER 15

By-Products and Waste

INTRODUCTION

POULTRY by-products include the remaining material after the edible meat has been sold. By-products include the offal, bone, blood, viscera, heads, feet and feathers. Today, most of the meat remaining on the bones, after the conventional hand deboning operation, is harvested by mechanical deboners, as described in Chapter 7. Two to three decades ago, the equipment was not available and most of this meat was not harvested; however, today, mechanically deboned poultry meat (MDPM) is an important commodity item around the world. The MDPM is used in the manufacturing of emulsion-type meat products (e.g., frankfurters) and can also be used in smaller proportions in ground meat products (e.g., sausages). Underutilized parts such as feet and heads, which used to be discarded in Europe and North America, are now receiving more attention. New markets are being developed and, often, such parts are frozen and sent across the ocean to markets where they can be sold for a marginal profit.

A big incentive in today's environmental situation is the recovery and reuse of as many by-products as possible. This is the result of higher land/field fees in crowded areas and an extra surcharge on treating wastewater with high levels of organic matter. Thus, the further processing industry tries to sell all meat, bone residues and other by-products to the pet food industry and sometimes even gives it away instead of paying for its disposal. It is expected that this trend will continue, and that the industry will keep on looking for ways to increase the added value of by-products. In order to reduce wastewater surcharges, most poultry processing plants have at least a primary separation operation for dewatering some of the offal material and screening the small meat pieces that contribute to high biological oxygen demand (BOD) values. It is also common today to separate the different components (e.g., feathers from offal) in order to process and/or sell them in a more profitable way.

Water discharge from poultry processing plants is a major issue for the industry, because relatively high volumes are used to process each bird (see Chapter 4). Veerkamp (1999) indicated that the total potable water used for processing a single bird varies between 5–20 L in the Netherlands, where air chilling is commonly used. In the United States, this amount can be twice as high because water chilling is the norm. Overall, 30–50% of the total daily water consumption is used for cleaning the plant and equipment. Veerkamp (1999) also mentioned that, over the past decade, there have been advances resulting in lower water usage. They include the application of more flat spray nozzles instead of showers, the installation of air-chilling operations and an increase in line speed, thereby lowering water usage per bird. On the other hand, however, the introduction of new regulations (e.g., HACCP) have increased the demand for cleaning of water. Overall, reducing water usage and potentially recycling some of the water (currently not permitted in various countries, but discussions have started in EC and other places) is important because the cost of freshwater and discharging wastewater have been steadily increasing over the past few decades. Environmental concerns have resulted in tighter regulations, in most countries, and strict limits have been placed on discharging untreated wastewater to streams, rivers, lakes and oceans.

Dewatering the wet by-products is one of the first steps in their recovery. For example, feathers can pick up about 10–15% water (Table 15.1) during scalding, defeathering, and later when water is used for washing feathers into a central location. Water quality in terms of microbial count and presence of pathogens is also becoming an important issue. Overall, the industry is trying to find new ways to treat and recirculate at least some of the water in order to increase efficiency and save on water costs.

The amount of by-product left after selling the dressed bird or cuts is derived from the average dressing percentages (carcass weight ÷ live weight × 100). Examples of some values are as follows (Mountney, 1989):

- turkey broilers—77%
- chicken broilers—70%
- duck (Peking)—58%
- pheasant—78%

Table 15.1. Percent Yield of By-Products from Turkey, Broilers and Fowl. Adapted From Lortscher et al. (1957).

By-product	Turkey	Broilers	Fowl
Offal	12.5	17.5	17.0
Feathers	7.0	7.0	7.0
Blood	3.5	3.5	3.0
Water Pickup During Processing			
Offal	—[a]	1.0	1.0
Feathers	7.0	15.0	13.0

[a] Not available

These numbers subtracted from 100 provide the percent of by-products. Based on poultry production data (reported in Chapter 1), it can be seen that the amounts left are significant. Therefore, by-products that can be sold to an interested party, such as a pet food manufacturer, represent an opportunity to recover some money. The components that cannot be sold actually represent added cost to the processor who must pay for their disposal.

This chapter will describe poultry industry by-products and some of the opportunities available to the processor in terms of selling them. Discussions of the pet food and rendering industries are also provided as well as basic information on wastewater treatment and reduction of organic matter found in wastewater.

FEATHERS

Feathers represent about 7% of the total live weight (Table 15.1). The feathers are made of a complex protein matrix and, as such, are a very rich source of protein (regular feather meal usually contains about 70–80% crude protein) that can be used for animal feed once the protein complex has been broken down. The feathers can also be used for bedding, ornaments, fertilizer, filler for chemical fertilizer and sporting equipment.

Fancy feathers such as pheasant's tail feathers, rooster neck hackles, tail and wing feathers from ostrich, roosters or turkeys should be removed before exposure to hot scalding water and separated from the other feathers. This involves manual labor that is more time-consuming and expensive than mechanical defeathering done by rotary rubber fingers. Conventional mechanical feather removal starts with the scalding operation (except in a Kosher operation; see Chapter 4), followed by using rotary rubber fingers. This is a fast and fairly efficient operation, but it can damage the shape and structure of the feathers (not a problem if the material is being used for bedding or animal feed). Feathers used for sporting equipment, such as for fetching arrows, are carefully hand selected to assure quality. It is interesting to note that feathers for an individual arrow must all come from either the right or left wing to provide proper rotation of the arrow (Mountney, 1989). Feathers can also be used for manufacturing of artificial fishing lures and as shuttlecocks used in badminton. Colored feathers are used for decorative purposes and sometimes are dyed and trimmed to a desired shape and pattern.

Feathers are usually classified as follows (Hardy and Hardy, 1949; Pacific Coast, 1997):

(*1*) Hard feathers—those with stiff quills, heavy vanes and a very small amount of fluff

(*2*) Saddle feathers—long narrow, vaned feathers from the saddle and back of the rooster

(*3*) Half fluff—vane feathers with fluff along the lower half of the quill
(*4*) Three quarters—fluff-vaned feathers with fluff along the lower three-quarters of the quill
(*5*) Fluff—body feathers with firm shafts bearing only fluff or the soft part of a feather
(*6*) Plumules—small down feathers with soft shafts, bearing only fluff
(*7*) Down—feathers without a shaft, composed of only a tuft of fluff

Cleaning feathers is done when feathers are to be saved for use in sporting equipment, bedding or clothing. If the feathers are going to be saved for more than a day, they can be soaked in a salt solution (about 5% NaCl) with some hydrochloric acid (0.3% HCl). Feathers are usually washed (five to eight times) with a mild soap solution and cleaning detergents to remove dirt, traces of manure and blood. A mild soap should be used to protect the essential oils in the feathers, and a neutral pH should be maintained to protect the feathers (Mountney, 1989). If feathers are not thoroughly cleaned, problems with mildew or degradation due to microbial activity can reduce their insulating properties and durability. Sometimes, a special high flash point gasoline is used to remove foul odors. In such a case, the processor can later lightly spray the feathers with mineral oil to replace some of the original oil. In some processes, where decolorization is required, blanching agents such as hydrogen peroxide, chlorine or potassium paramenganate are used.

Feathers used for bedding, are thoroughly cleaned, dried and later sorted. Down is the most preferred material because it possesses a unique structure that allows it to hold large amounts of air (relative to its weight) and is actually designed to provide lightweight insulation for the bird. Waterfowl down, such as duck and goose, is considered superior. The down usually represents 12–15% of the total weight of the feathers in waterfowl. The remaining feathers are actually designed to let air and water slip over them and not be trapped within their structure. This is obviously essential for the bird's ability to fly. The structure of a down feather is shown in Figure 15.1. A structure of a regular feather is provided in Chapter 2.

After washing and rinsing the feathers, they are blown- or steam-dried to encourage fluffing, which enhances the feather characteristics as a bedding material. In addition, the process provides lightweight feathers and increases the insulation efficiency of the feather. Breathability, compressability and the ability to return to its original shape and volume are also important characteristics in selecting feathers for bedding (Mountney, 1989). An important measurement of the feather's quality is called fill-power or "loft." This is basically a measurement of the amount of space the feathers/down will fill under a standard pressure. Because one of the major requirements for feathers used for bedding and insulation is maximum volume when in use and minimum volume for storage, the fill-power test is very useful. A high fill-power

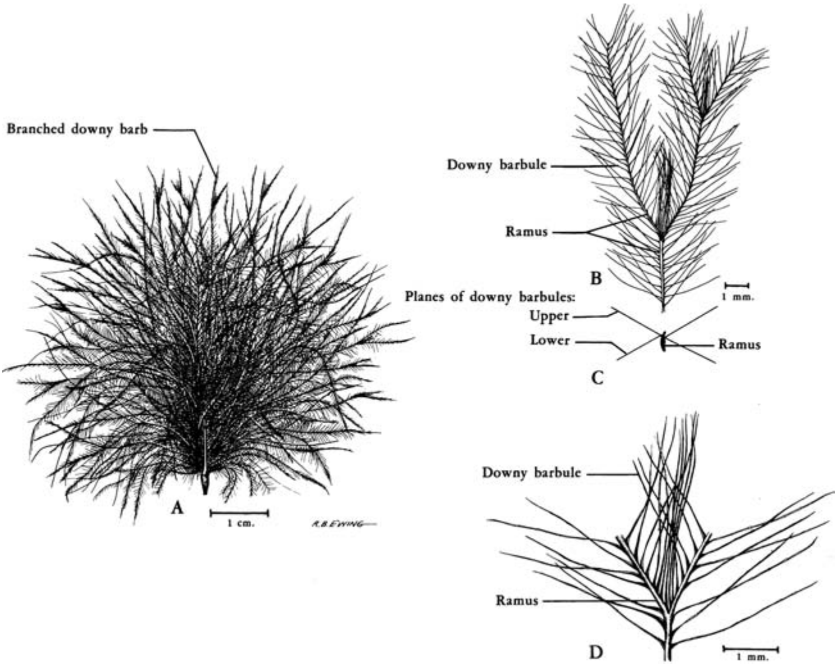

Figure 15.1. *Structure of a Down Feather. From Lucas and Stettenheim (1972).*

is found in goose down, which is usually higher than duck down when obtained from birds of similar age. A high fill-power of 750 in^3/oz indicates that the feathers are strong, have high insulating efficiency, high durability, softness, little loss of resiliency over time and sustainability. A lower fill-power of about 300 in^3/oz indicates smaller clusters of down, lower resilience and faster wear out.

The use of down for bedding has declined over the past few decades due to the introduction of synthetic fibers; however, a surge of high-end down-filled bedding has been seen within the last few years. Overall, high-quality down is four times as thermally efficient and ten times as durable as synthetic materials (Ockerman and Hansen, 2000). Bird's feathers are classified as a natural product, contain no toxins, use no toxins to produce, do not pollute and are biodegradable (Pacific Coast, 1997).

After washing, rinsing, steam blowing and drying, feathers are sorted into different size groups. This is done by air currents that blow the down and feathers through a series of vertical buffles, suspended from both the top and bottom of the separator, where the lighter down feathers are blown further away than the heavier feathers (Pacific Coast, 1997). According to U.S. regulations, a product identified as down must contain 80% down and no more than 20% feathers. This distinction was made because it is almost impossible to get a complete down separation as some light feathers, usually no longer than 6 cm, will also be blown into the down compartment.

Feathers used in animal feed are usually hydrolyzed to break down the complex protein (keratin) structure, otherwise they would remain indigestible. Because feathers are mainly composed of protein, they represent a good source of dietary protein for animal feed. The feathers are washed to remove dirt and then dewatered. Table 15.1 shows that feathers will commonly pick up between 7–15% moisture during the scalding and defeathering operations. After some of this water is removed (usually by compression), the feathers are cooked for 1–2 hours in order to hydrolyze the complex protein structure. Heating is commonly done under pressure (2–3 Atm) that results in a temperature of >100°C, thereby increasing the hydrolysis rate. The feather's digestibility is related to the cooking temperature and time, where higher temperatures result in higher amino acid availability. The cooked feathers are then dried by air and ground, resulting in a product known as feather-meal. As with other feed materials, the feather-meal is passed through a metal detector (see Chapter 8 for technical information) to ensure that no metal objects are present. The common composition of a feather-meal is as follows:

- 75% crude protein (some contain up to 90%)
- 10% moisture (maximum)
- 3–4% fiber (maximum)
- <6% fat (maximum or minimum as specified)

The grind size should be such that 100% of the particles pass through a U.S. No. 7 screen and 95% through a U.S. No. 10 screen. The meal is rich in sulfur-containing amino acids, such as cysteine, and is also rich in arginine and threonine but is deficient in histidine, lysine, methionine and tryptophan. When the meal is fed to monogastric animals, such as poultry or swine, the limiting amino acids should be supplemented. The common feeding level is 0.5–1.5% of the diet (Ockerman and Hansen, 2000). When fed to ruminant animals (beef cattle), feather-meal efficiency can be improved by urea supplementation.

OFFAL AND BONE

The classification of offal varies in different countries. In North America, the meat industry considers everything produced by or from the animal, except dressed meat, as a by-product or offal (Ockerman and Hansen, 2000). In this category, there are the "edible" and "inedible" parts. The former includes a variety of meats such as livers, hearts and gizzards that are referred to as the giblets in the poultry industry (see Chapter 4). Blood, which sometimes is used as an edible item, is also included in this category. The inedible portion includes parts such as the viscera (gut), heads and bones that are commonly sent for further processing into pet food, growing fur-bearing animals (e.g., mink), and feeding fish and hogs. Because of the danger of transmitting pathogenic organisms to other animals, the offal is usually cooked at a high temperature (>100°C, under pressure) to ensure the destruction of all pathogens. The process of heating and rendering is described below. The treated offal material is usually high in protein and can be mixed with other ingredients (e.g., cereal, vitamins) to produce a balanced pet food diet.

THE PET FOOD INDUSTRY

The pet food industry represents a significant market for rendered poultry by-products. In the United States, the pet food industry expanded by almost 60% between 1988 and 1996. Figure 15.2 shows the growth in sales of dog and cat food between 1990–1998, which reached $9.5 billion in 1998. This figure does not include retail sales from kennel/veterinarian outlets that are estimated at more than $500 million/year in the United States alone. Since 1990, the industry has experienced an estimated 4.1% annual growth, with cat food experiencing most of the growth (6.5%) and dog food an annual increase of 2.7%. This obviously represents a tremendous increase in the sale of pet food and the development of a fairly new market. Ockerman and Hansen (2000) mentioned that the first commercially prepared dog biscuit was introduced in England in 1860. Canned cat food and dry meat dog foods were only introduced in the United States by 1930. In the 1950s, new expanded pet food products were introduced and, in the 1960s, semi-moist pet food was introduced. Today, it is estimated that over 1 million tons/year of poultry, red meat and seafood by-products are used by pet food manufacturing industry alone. This provides the meat industry with a good and stable source of income, as

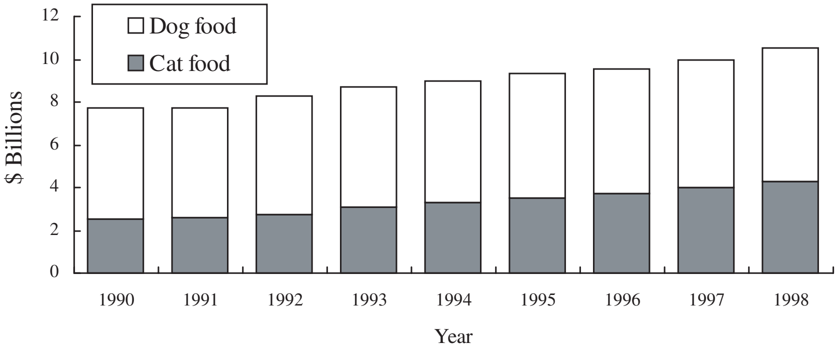

Figure 15.2. *Growth in Retail Pet Food Sales in the United States from 1990–1998. From Hoepker (1999). Based on Estimates from Maxwell, J. C., Davenport Co.*

well as high-quality and nutritious pet food for pet owners. The by-product side of the poultry industry has actually enjoyed a growing market over the past few years as a result of fish stocks declining, meaning less by-products from the seafood segment.

When considering the high percentage of households keeping a pet in the United States (56 million dogs and 68 million cats in 1997), it is easy to understand how the pet food industry has grown so quickly. Overall, the U.S. pet population has steadily increased by 1.3% annually from 1990–1997 (cats 1.7% and dogs 0.7%), and it is predicted that steady growth will continue (Hoepker, 1999). It is estimated that there are currently over a thousand different pet food items on the U.S. market. Australians, who have one of the highest incidences of pet ownership in the world (66% of the country's households), spent about $1.15 billion on pet food in 1998. Germans spent an estimated $2.2 billion in 1998. Growth in pet food retail sales are expected to increase by around 4% annually in Japan, where people own more than 10 million dogs and 8.5 million cats. It is interesting to note that the growth in sales is expected to be due to changing social trends rather than an increase in the number of pets. Some of the changes mentioned include the development of pet superstores (similar to the ones introduced in the United States in the early 1990s), development of premium pet foods and increased awareness/knowledge of feeding pets a nutritionally balanced diet. Overall, the pet food market is becoming more competitive as more companies realize the potential for growth and profit. Hoepker (1999) estimated that in the United States, grocery stores experienced a margin of around 20–22% on pet food sales in 1998. However, with increasing market competition of mass merchants, who experienced a margin profit of 16–19% in 1998, overall pet food margins are expected to shrink.

The meat industry is shipping the raw by-products to the pet food manufacturer fresh or frozen; the latter is used in case of delays between shipping and processing. The material is extensively cooked and then mixed with other ingredients to produce a balanced diet for different pet food categories. Ingredients such as cornmeal, soybean and vitamins are commonly added. Examples of labels appearing on three types of pet foods are provided below:

CANNED CAT FOOD

Ingredients: chicken and chicken by-products, meat by-products, vitamins and minerals, vegetable gums, natural flavors, natural colors, caramel and water added for processing.

Protein (min)	*8%*
Fat (min)	*4%*
Moisture (max)	*82%*
Ash (max)	*2.5%*

CANNED DOG FOOD

Ingredients: poultry by-products, meat by-products, chicken, ground wheat gluten, minerals and vitamins (calcium, potassium, zinc, iron, iodine, vitamins A, B1, D and E), bonemeal, citrus pectin, guar gum, sunflower oil, tripolyphosphate, natural flavors.

Protein (min)	*8%*
Fat (min)	*6%*
Crude fiber (max)	*1.5%*
Moisture (max)	*78%*

DRY DOG FOOD

Ingredients: ground corn, wheat shorts, poultry by-product meal, corn gluten, soybean meal, poultry fat preserved with mixed tocopherols (to preserve flavor), rice, molasses, tripolyphosphate, dry whey, calcium carbonate, salt and vitamins.

Protein (min)	*22%*
Fat (min)	*10%*
Crude fiber (max)	*5%*
Moisture	*10%*

The first example illustrates a formula based on meat (listed as chicken) and meat by-products that is fortified with vitamins and minerals. Ingredients are listed in descending order as is done with other foods. The requirements for the nutritional content labeling are not as stringent as for human food; the pet food manufacturer can only declare minimum protein content and does not have to provide a list indicating the amount of vitamins and minerals (Note: fortified human food must have a precise declaration of all ingredients.)

The second example illustrates an added cereal component that is used to improve the texture, add bulk and crude fiber (plant material) to the formula. It also contains two different gums (pectin, guar) to assist in texturizing the product. Natural flavor ingredients, usually poultry or beef extracts, are also included.

The third example illustrates a formula that is mainly based on cereal products that provide a high percentage of carbohydrate, but also provide some protein. Poultry by-product meal is included as a main protein and mineral source. The poultry fat, which is prone to oxidation, especially during cooking and later storage, is protected by antioxidants (tocopherols).

The protein content of pet food can range from 12–50% depending on the way it is sold. Canned food usually has about 12–14%, semisolid food 21–25% and dry food 20–50% protein. It should be mentioned that today, pet food companies invest substantial amounts of time and money to explore the nutritional needs, as well as flavor and textural preferences (e.g., ground, chunked) of different animal groups. Sophisticated processing equipment such as extruders are often used to texturize and shape the product to make it more attractive and palatable in this highly competitive pet food market.

RENDERING

Rendering animal by-products has been practiced for many centuries. One of the major prehistoric applications of rendered products was the use of fats and oils from animals to waterproof clothing. Later, people used animal fat for soap production and candle making. Some of the early documented evidence for soap production goes back to the Babylonians in 2800 BC. Later evidence showed that the Phoenicians and Romans were also knowledgeable in the art of soap making, which was performed by experienced individuals operating small-scale shops.

The real development of an industrial-scale rendering appeared during the early 19th century (Dainty, 1981). The main item was a fertilizer that was prepared from animal by-products arriving from slaughterhouses and dead animals. Prior to that, this material was buried and had no economical importance. Later, it was realized that the meat industry could recover some money by transforming the waste material into farm fertilizers. It should be noted that burying the material actually cost the meat processor money in terms of transportation, labor and landfill costs. Today, the rendering industry produces hundreds of useful products that are generally divided into edible and inedible oils, chemicals, meat meals and bonemeals. These products are produced from all kinds of animal by-products including viscera, bones, trimmings, feathers and dead stock.

Some of the large poultry processing plants have their own rendering facilities, where other medium and small plants rely on independent rendering contractors who collect and process the material. There are different rendering systems that can generally be divided into four categories: autoclave or wet rendering, dry batch, dry continuous processing and continuous low-temperature system (Ockerman and Hansen, 2000).

- An *autoclave system* includes a cooker filled with pre-ground raw materials that are hermetically sealed, and then steam is injected into the chamber at about 140°C. The treatment usually lasts 3–4 hours, and at the end, pressure (360 kPa) is reduced to atmospheric pressure (about 100 kPa). The slow pressure reduction is important to avoid emulsification of the fat within the aqueous fat phase. The cooled material is removed, and the free-flowing fat component is drained. The remaining moist material is then pressed to remove the moisture by either a batch-type hydraulic press, a continuous screw press or a decanter centrifuge. Figure 15.3 shows a wet rendering process where, after heating, the liquid is removed by a centrifuge and then fat and water are separated by a high-speed, three-phase separator.
- A *dry batch system* consists of a cooker with steam jacketed walls, so steam does not come in direct contact with the material inside. Some-

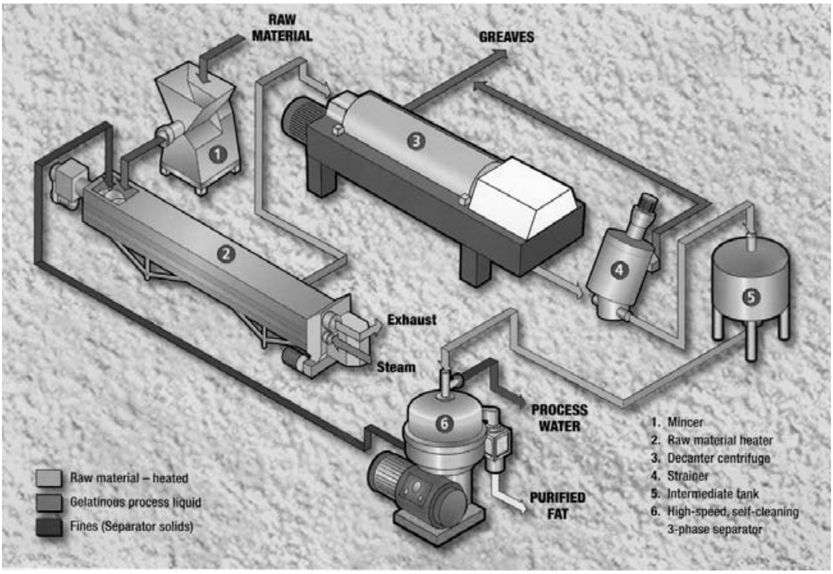

Figure 15.3. *A Diagram Showing a Wet Rendering System for Processing of Meat By-products. Complimentary of Alfa-Laval, Scarborough, ON, Canada.*

times, a hollowed steam-filled agitator is employed. Ground material, usually >2.5 cm, is batch fed into the system. During this process, water is released from the product as well as the fat; however, the fat is not severely degraded by live steam, as is the case in the previous system described. After cooking, the material is subjected to treatments described above for the autoclave system.

- A *continuous dry system* is similar to the dry batch rendering system, but the material is continuously fed into the system and treated under atmospheric pressure. The cooker is usually horizontal and has a steam jacket and possibly a hollowed, steam-heated agitator. Basically, the material enters at one end and exits at the other in a continuous fashion. The time the material is exposed to heat depends on the size and retention volume of the cooker. The discharged material is dumped into a percolator that consists of a tank with a strainer at the bottom. The free fat is drained, and later, the material is pressed to remove the extra fat. The solids remaining are pressed and ground into a meat meal.
- A *continuous, low-temperature rendering system* employs mechanical means to remove the fat and moisture. Therefore, it is sometimes called a mechanical dewatering system. In the process, the raw material is ground and then passed to a low-temperature, dry or wet cooker (also called pre-heater or coagulator), where the material is heated to 60–90°C in about 10–30 minutes. This causes some of the fat cells to

break. The material is then pressed, using a continuous screw-type press, and the fat along with the water are extracted. The remaining solid material is then centrifuged for additional water and fat removal. This process results in a lower heat treatment and reduced energy costs compared to the other processes mentioned above.

WASTEWATER TREATMENT

Water used for scalding, washing carcasses, salvaging giblets and cleaning the plant cannot simply be discharged into lakes and rivers because of the relatively high content of organic matter such as protein and fat (see total suspended solids values in Table 11.1) and the microorganisms present. The processor can discharge wastewater into the municipal sewage system; however, high costs for treating the elevated load of organic matter can be expected. Usually, it is in the best interest of an individual poultry processing plant to treat the water, as much as possible, prior to discharge. Different procedures can be used, ranging from simple filtration to sophisticated aerobic lagoons. Usually, capital and operating costs determine to what extent a plant would treat its wastewater prior to discharge. The increase in environmental awareness, over the past two decades, has put additional pressure on the industry to treat wastewater and look at ways to reduce water consumption (e.g., recycling). This is most evident in sales pitches for processing equipment, where manufacturers are emphasizing water savings that can be achieved with their new equipment.

The different steps that can be included in treating wastewater are shown in Figure 15.4. As mentioned above, the processor may choose to install one or all of the components shown in the figure. The decision is based on capital cost, expected operational cost, amount of wastewater, local and federal regulations regarding pollution, expected charges for wastewater treatment by the municipality and expected production figures for the plant. Usually, a processor will first estimate the costs by conducting a survey, prepared by a qualified expert/consultant who can determine the scope of the operation required and provide projected capital and operational costs.

The main criteria used by municipalities to calculate surcharges for wastewater treatment are based on the organic matter present. Some of the common methods include the following:

- *Biological oxygen demand (BOD)* is a semiquantitative measure of the organic content in wastewater and is used to estimate the amount of oxygen that will be consumed during microbial degradation of the affluent. The common term of BOD_5 refers to the amount of oxygen (in ppm) required to decompose the organic matter by aerobic microorganisms in a

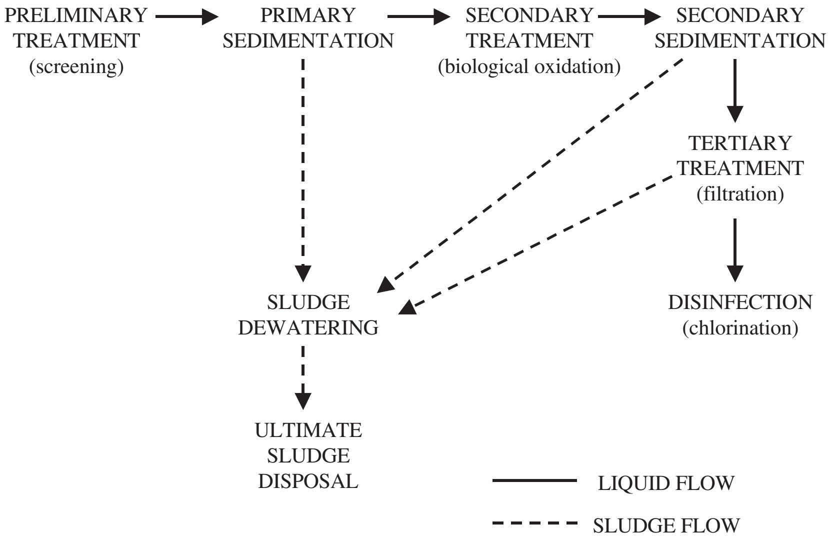
PRELIMINARY TREATMENT (screening)
PRIMARY SEDIMENTATION
SECONDARY TREATMENT (biological oxidation)
SECONDARY SEDIMENTATION
TERTIARY TREATMENT (filtration)
SLUDGE DEWATERING
DISINFECTION (chlorination)
ULTIMATE SLUDGE DISPOSAL
LIQUID FLOW
SLUDGE FLOW

Figure 15.4. *Flowchart of Potential Wastewater Treatments Used by a Poultry Processing Plant. Note: A Processor can Install One or More of These Components.*

wastewater sample during a five-day period. Note that the decomposition can take more than five days, but this is a common index used to express the amount of organic matter present in the water. Parker and Litchfield (1962) estimated that wastewaters from meat processing plants have a BOD_5 of 1,100 ppm. Packing house and stockyard wastewaters usually have a BOD_5 value of 600, and domestic sewage, which contains no industrial waste, has a value of approximately 200 ppm.

- *Chemical oxygen demand (COD)* is another test for measuring pollution by using an oxidizing compound (dichromate, $K_2Cr_2O_7$) acid reflux method. This is a faster test that also measures nondegradable organic compounds such as cleaning solvents. Although there is some overlap with the BOD_5, it does not duplicate it, and usually, unless a COD/BOD ratio is reported, regulatory agencies will not accept COD data by itself.
- *Total organic carbon (TOC)* is another method that determines the amount of CO_2 released from catalytic oxidation at 900°C. This is a rapid method that correlates fairly well with the standard BOD_5. However, the method requires sophisticated laboratory setup.
- *Total oxygen demand (TOD)* measures the amount of oxygen required for combustion of all the material in a water sample brought to 900°C.
- *Dissolved oxygen (DO)* determines the amount of oxygen present in the water, which is important during a secondary wastewater treatment (see Figure 15.4—biological oxidation, usually done in an aerated

lagoon). This can be determined by an electrode submerged in a sample or an iodometric titration.

- *Suspended solids (SS)* is a common method used to measure the total nonfilterable residue that is retained by a membrane filter (glass or fiber) after filtering a predetermined volume of wastewater. The solids are then dried for an hour at a temperature of about 105°C. Parker and Litchfield (1962) reported values of about 820 ppp for wastewater from meat plants and about 600 ppp for wastewater from packing houses and stockyards.

Treating wastewater coming out of a food processing plant follows a logical sequence. It starts with crude screening of meat chunks/particles (size measured in cm) and ends with breaking down dissolved organic matter (nanometer size) by microorganisms. The following section will discuss the different stages outlined in Figure 15.4.

Preliminary treatment is designed to remove large particles by a coarse screen that can detain matter such as feathers, meat chunks, etc. Figure 15.5 shows a simple screening configuration. As simple as it looks, such a system is extremely useful in substantially reducing the BOD_5 value (Figure 15.6). The solids collected can be dewatered by compression and later sent to a rendering plant or to a landfill for solid waste disposal. It is important to try and remove the organic matter fairly quickly before excessive microbial degradation/fermentation and odor production takes place (Green and Kramer, 1979). If a composting procedure is used, it is important that the material be allowed adequate exposure to microbial attack, as will be discussed at the end of the chapter.

Primary treatment is designed to remove small particles from the water. Also, in this case, relatively inexpensive equipment can be effectively used to

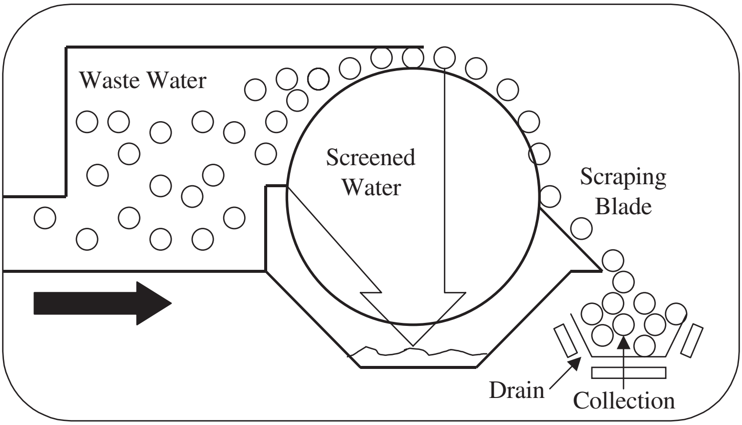

Figure 15.5. *Pretreatment of Wastewater Discharge Used to Separate Solids (e.g., Feathers, Meat Scraps) from Water by a Self-Cleaning Rotary Screen.*

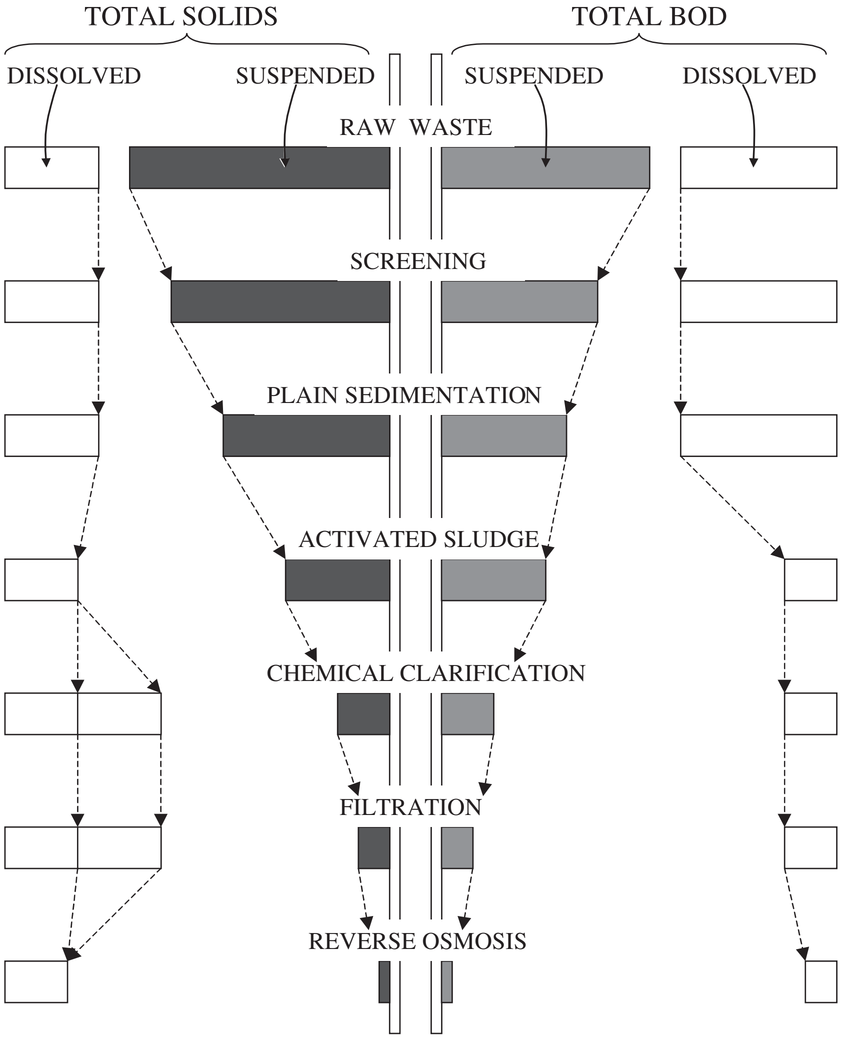

Figure 15.6. *Removal of Solids and BOD, Showing the Effect of Treatment upon the Removal of Solids and BOD. Redrawn from Hill (1976).*

separate the heavy particles by sedimentation and the very light particles, such as oil and grease, by floatation. Figure 15.7 shows an example where a combination of sedimentation and floatation are used. In this case, a longer dwell time is used to allow the small particles to settle. Later, the particles are scraped by a moving belt equipped with paddles into a collection area. The material is collected into a lower pit and then removed by a pump. Certain chemical compounds such as lime, alum and $FeCl_3$, or special polymers can

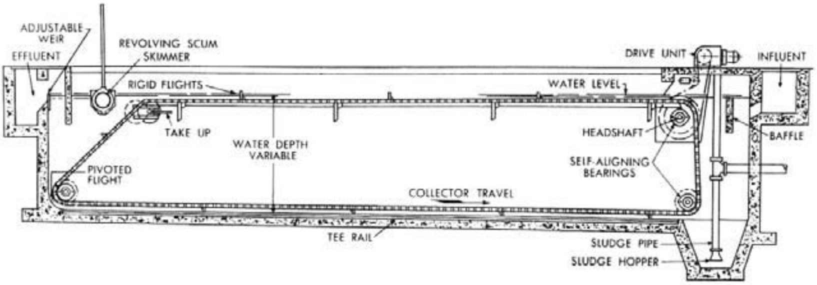

Figure 15.7. *An Example of a Primary Wastewater Treatment. Sedimented Sludge (e.g., Dirt, Crop Content) is Scraped to a Pit at the Bottom, while Floating Material (e.g., Fat, Feather Fragments) is Skimmed Off at the Top. Courtesy of USFilter's Envirex Products, Waukesha, WI, U.S.A.*

be added to speed up solid separation. Floating particles are skimmed at the top and then sent into pet food production or landfill disposal. During the primary treatment, a substantial amount of particulate material can be removed, and the BOD_5 is reduced by about one-third (Figure 15.6). Using floatation for small fat particles and liquid oil is fairly simple. In some operations, this process is sped up by using chemicals that promote flocculation with or without the introduction of air bubbles that assist in carrying the light particles to the top. The material that floats to the surface is then removed by a continuous skimming device as shown in Figure 15.8. Energy costs are fairly low because gravity and flotation are used.

Secondary treatment relies on biological (i.e., microorganisms) breakdown of dissolved organic matter. Such a treatment can range from anaerobic lagoons to advanced activated sludge processes. This stage is designed to remove suspended organic matter by microorganism degradation and the production of gases (e.g., CO_2) and water and an increase in the biomass of the microorganism. The biomass can later be filtered out in a much more cost-effective way than trying to remove dissolved organic matter. Figure 15.9 shows an example of an activated sludge system where a floating mechanical aerator is used to introduce oxygen into the water, in a so-called aerobic lagoon. The introduction of atmospheric oxygen enhances the biological oxidation and maintains an environment of dissolved oxygen in the range of 1–3 mg/L. The aerator device also helps to keep solids in suspension (Marriott, 1999). Aerobic lagoons, which rely on microbial degradation (in the presence of oxygen), can be up to 3 m deep. Usually about one-fifth of the BOD sent is converted to sludge solids. The total reduction in BOD is usually about 70–90%. The solid sludge can later be removed in a so-called polishing pond or sand filter. Anaerobic lagoons are the ones where no oxygen is introduced. The organic matter is mainly degraded by anaerobic bacteria that produce biomass, water and gases such as CO_2, CH_4. The depth of such lagoons is

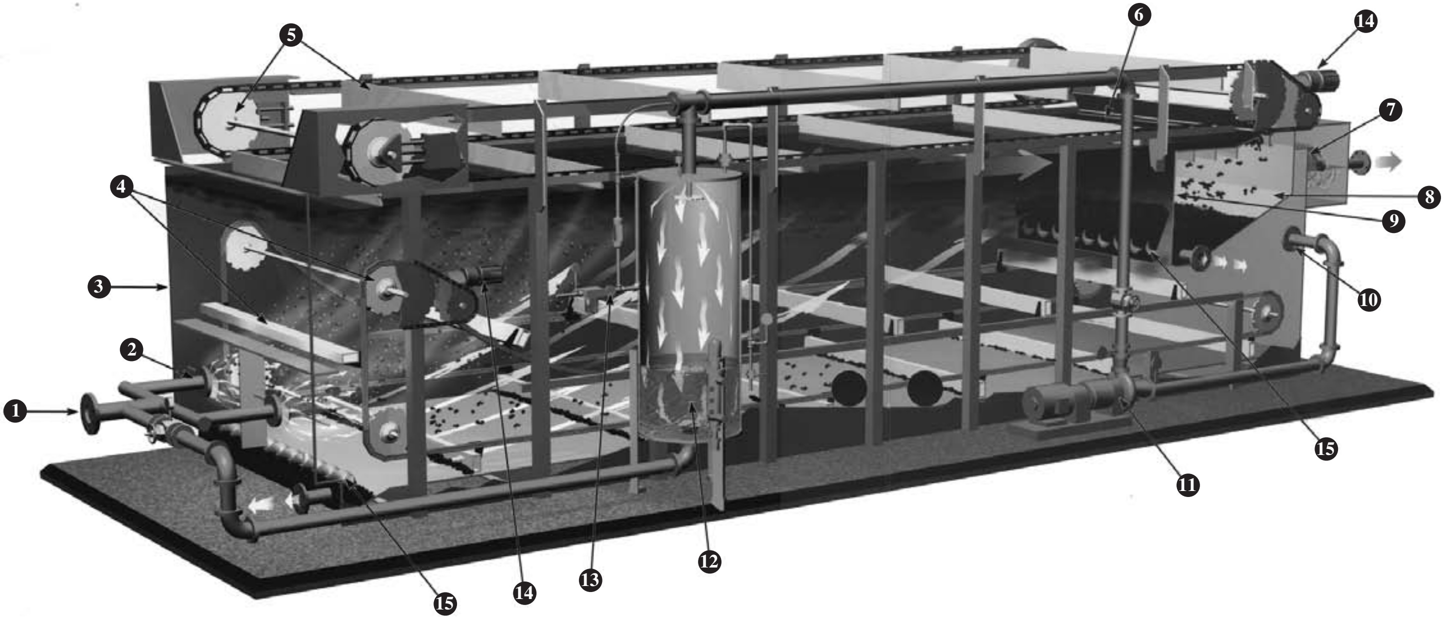

Figure 15.8. *An Example of an Air Flotation Tank (Primary Treatment) Used to Speed Separation by Adding Chemicals to Encourage Flocculation. Air Bubbles Later Assist in Carrying the Particles to the Top Where They are Skimmed Off. Parts are 1) Sludge Inlet Piping, 2) Blending and Distribution System, 3) Float Treat Thickener Tank, 4) Positive Grit Removal, 5) Skimmers, 6) Skimmer Beach, 7) Effluent Weir, 8) Thickened Sludge Trough, 9) Sludge Retention Baffle, 10) Source of Pressurized Flow, 11) Recycle Pump, 12) Recycle Saturation Tank, 13) Airline, 14) Drive Mechanisms and 15) Screw Conveyor. Courtesy of USFilter's Envirex Products, Waukesha, WI, U.S.A.*

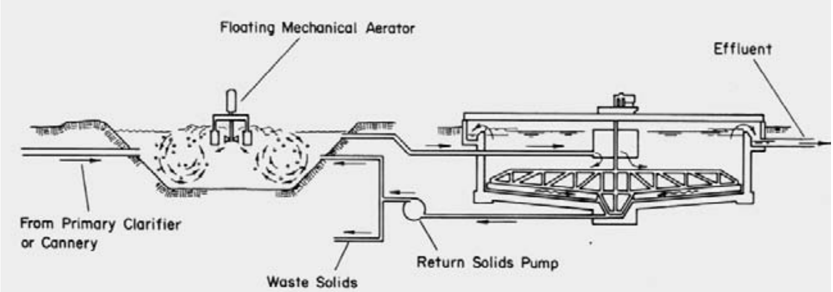
Floating Mechanical Aerator
Effluent
From Primary Clarifier or Cannery
Waste Solids
Return Solids Pump

Figure 15.9. An Example of an Activated Sludge System. From Hill (1976).

usually 2.5–3 m. Construction requires relatively low capital investment and operating costs are minimal because no mechanical agitating devices or air bubbling equipment are required. Loading rates are usually in the range of 250–1,100 kg/hectare/day, where temperature is an important factor in the rate of organic matter loading capacity. In such lagoons, a BOD_5 reduction efficiency of 60–80% can be expected within 0.5–3 weeks when temperature is ≥22°C (Marriott, 1999). Trickling filters consist of stationary media, such as rocks, that are arranged above an overdrain. The wastewater passes by, and aeration is achieved by exposure of the large surface area of the flowing water to the air. Bacteria are attached to the stationary media and consume the organic matter. Figure 15.10 shows a trickling filter system where the microorganisms are actually attached to a rough, plastic media while the water trickles from above. The water then passes through a clarifier that helps collect the biomass (as waste solids), while the water from the top is discharged.

Tertiary treatment is applied to the water in order to remove odors, flavoring compounds and color. Sand filters (Figure 15.11) are very common for physical separation and removal of some of the small color and odor compounds. Acti-

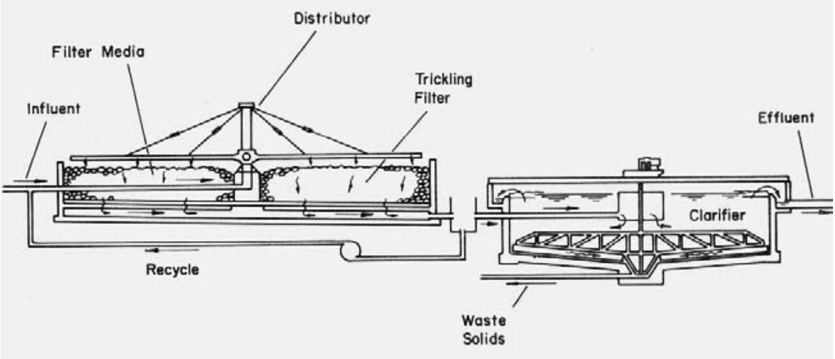

Figure 15.10. An Example of a Trickling Filter System. From Hill (1976).

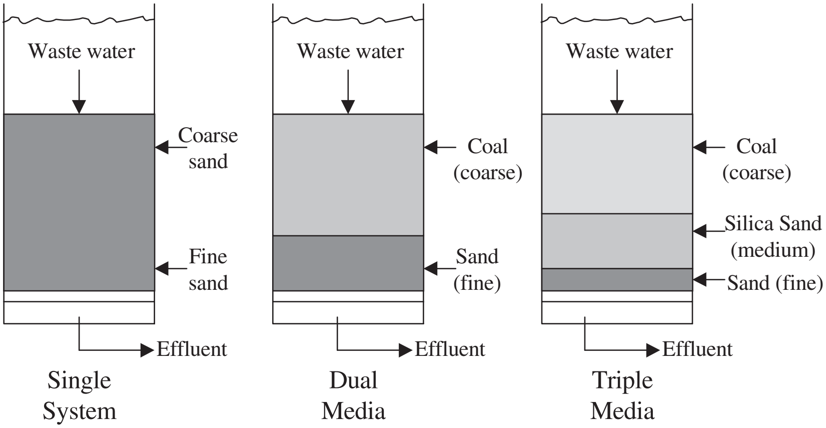

Figure 15.11. *Examples of Tertiary Sand/Gravel Filter Treatment.*

vated carbon or coal can be used to remove such compounds because it has a high affinity for organic matter. A layer of activated carbon can be inserted at different stages of the operation (Figure 15.11). The activated carbon should be replaced on a regular basis because after reaching maximum load capacity, it becomes ineffective. Sand filters should be cleaned on a regular basis, usually by back flushing. In a commercial setting, one might see a series of such filters where some are used, while others are cleaned by back flushing. Part of the tertiary treatment can also include an ion exchange unit or even an electrodialysis unit where minerals, especially from plants discharging brine solutions, are removed.

Disinfection is performed for public health reasons as the last stage to treat the water prior to discharging to rivers, lakes, etc. Chemical agents such as chlorine and H_2O_2 are commonly employed to kill pathogenic microorganisms. It is more efficient to treat the water after most of the microorganisms have been removed by a secondary or tertiary filtration treatment (Figure 15.11). Disinfection can be done at an earlier stage, but because the high organic matter load can react with the disinfecting agent and render it ineffective, it is recommended to employ this stage when organic and microbial loads are the lowest. [Note: the phenomenon that disinfecting agents, such as chlorine, react with organic material is similar to the situation described in a poultry water chiller (see Chapter 4) where chlorine is added.] Disinfection by gases such as ozone (O_3) and chlorine oxide are also employed, as well as physical means such as ultraviolet light, microwave and gamma radiation.

The progressive reduction in BOD_5 and total suspended particles is shown in Figure 15.6, where it is easy to see that the first few steps, which include simple physical screening (preliminary treatment) and plain sedimentation (primary treatment), are very effective. Later treatments are used to remove the smaller size components and usually take more time and money to achieve.

Based on an early feasibility study, the poultry processor can decide which wastewater treatments to do in-house and at what stage to purchase the services of the local municipality. In most cases, it is recommended that even a small processor install a primary and possibly a secondary wastewater treatment to effectively reduce outside charges for cleaning the plant's wastewater.

Disposal of solid waste is usually done by trucks carrying the de-watered sludge or other solid waste to a municipal dump where it is properly buried or composted. Simply dumping solid waste near the processing plant can cause serious odor problems, spread of diseases through wildlife, insect manifestation and potentially pollute groundwater. Most countries have strict regulations regarding waste disposal. Composting is becoming a more popular alternative today because fast-filled landfills are a problem. Stabilizing the organic matter through microbial activity provides humus that can be used as a farm fertilizer and to improve soil texture. Using an inoculum of selected aerobic thermophilic bacteria is recommended because it can speed the process and result in a better quality humus product. During the composting process, the solid waste should be aerated on a regular basis by inverting or mixing the material. If the waste material is too dense or comes in large chunks, it is recommended to have it ground so that surface area exposed to microorganisms and air is higher. The composting area should be well managed and fenced to prevent wildlife (birds, mammals) from getting in. The process can be completed within 10–25 days depending on factors such as temperature, aeration and inoculation level.

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